PORTLAND CEMENT ASSOCIATION

SOIL-CEMENT CONSTRUCTION

Handbook

The activities of the Portland Cement Association, a national organization, are limited to scientific research, the development of new or improved products and methods, technical service, promotion and educational effort (including safety work), and are primarily designed to improve and extend the uses of portland cement and concrete. The manifold program of the Association and its varied services to cement users are made possible by the financial support of over 65 member companies in the United States and Canada, engaged in the manufacture and sale of a very large proportion of all portland cement used in these two countries. A current list of member companies will be furnished on request.

SOIL-CEMENT CONSTRUCTION

Handbook

PORTLAND CEMENT ASSOCIATION 33 West Grand Avenue Chicago 10, Illinois

foreword

SOIL-CEMENT is a tightly compacted mixture of pulverized soil, portland cement and water that, as the cement hydrates, forms a hard, durable, low-cost paving material.

Primarily used as a base course for road, street and airport paving, soil-cement was developed on the premise that low first cost depended on using inexpensive local materials to the fullest extent. Paving engineers had long recognized the need for such a material because of the obvious saving in road-building costs that could be had by utilizing the soils on or near the construction site.

Through the years many efforts were made to combine soil and cement to produce a satisfactory low-first-cost paving material. The idea dates back to 1917, when Dr. T. H. Amies of Philadelphia, Pa., obtained a patent on a material that he called "Soilamies." In 1920 a patent was issued on "Soil-crete," a material that involved the addition of a "magic crystal" to each bag of cement. About 1922 the Iowa and South Dakota state highway departments mixed cement with roadway soil, and in 1924 the Ohio state highway department incorporated cement in subgrade soils to increase stability. About the same time, short roadway sections of soil and cement were tried in California and Texas. But soil science as applied to road building was new at that time and these trials resulted in unpredictable and varied results.

Of special significance to the development of soil-cement was the pioneer work of the South Carolina State Highway Department, initiated in 1932. During 1933 and 1934, five short sections of highway were built with soil and cement. The results of this work were most promising and provided the stimulus for extensive research on soil-cement mixtures by the Portland Cement Association, starting in 1935. The investigation culminated that same year in construction of a 1½-mile scientifically controlled experimental soil-cement project—a cooperative effort of the South Carolina State Highway Department, the U.S. Bureau of Public Roads and the Portland Cement Association. The results of this work prompted other highway departments to build experimental soil-cement roads and in 1936, projects were built in Michigan, Illinois, Wisconsin and Missouri.

In comparison with today's standards, the methods used in building these experimental projects were crude at best. Yet nearly all of these early roads are still carrying traffic.

Although construction methods have been improved tremendously, the same basic engineering principles are still in use today. The continual growth and acceptance of soil-cement is the result of the combined efforts of many state, county and city highway departments, government agencies, equipment manufacturers, contractors, consulting engineers, testing laboratories and individuals.

Many thousands of miles of soil-cement paving have been constructed in the United States and Canada. Following American practices, many foreign countries have also done extensive research and have built many miles of low-cost soil-cement paving.

contents

Hereafter, compacted soil-cement will be referred to simply as soil-cement since it is by far the most commonly used type of soil and cement mixture. Other terms, such as "cement-treated base," "cement-stabilized soil" and "stabilized aggregate," are sometimes used. For the purposes of this handbook all mixtures of soil and cement are classified as soil-cement or cement-modified soil without regard to the type or source of soil or aggregate.

Cement-modified soil is an unhardened or semihardened mixture of soil and cement. When relatively small quantities of portland cement and moisture are added to a granular soil or a silt-clay soil, the chemical and physical properties of that soil are changed. Cement reduces the soil's plasticity and its water-holding capacity and increases its bearing value. The degree of improvement depends on the quantity of cement used and the type of soil. In cement-modified soil, only enough cement is used to change the physical properties of the soil to the desired degree—less cement is used than is required to produce a hard soil-cement. Cement-modified soils may be used for base courses, subbases, treated subgrades, highway fills, and as trench backfill material. Cement-modified soils and their uses are discussed further in Chapter 8.

Plastic soil-cement is also a hardened mixture of soil and cement that contains, at the time of placing, sufficient water to produce a consistency similar to that of plastering mortar. By comparison, compacted soil-cement is placed with only sufficient moisture to permit adequate compaction and cement hydration. Plastic soil-cement is used to pave steep, irregular or confined areas such as highway ditch linings and other erosion-control structures, where it is difficult if not impossible to use road-building equipment.

The application of compacted and plastic soil-cement for paving slopes and lining ditches is given in a separate information sheet.*

characteristics of soil-cement

During construction the soil-cement mixture is compacted to a high density. As the cement hydrates, the mixture hardens in that state and therefore does not consolidate further under traffic, or rut or "shove" during spring thaws. Hard soil-cement has the capacity to bridge over local weak subgrades. It does not soften

***Soil-Cement for Paving Slopes and Lining Ditches*, available free upon request only in the United States and Canada from the Portland Cement Association.

Fig. 2. Proof of soil-cement's strength was given by this road in Madison County, Tenn., when a washout left an unsupported section of soil-cement 8 ft. long and 4 ft. wide.

when exposed to extreme wetting and drying or freezing and thawing. Since soil-cement is a cemented, hardened material it has greater load-carrying capacity than other low-first-cost paving materials.

materials for soil-cement

Only three basic materials are needed in soil-cement: soil, portland cement and water. Low first cost is achieved mainly by using cheap local materials. The soil, which makes up the bulk of soil-cement, is either in place or obtained nearby, and the water is usually hauled only short distances.

The word "soil" as used in soil-cement means almost any combination of gravel, sand, silt and clay, and includes such materials as cinders, caliche, shale and chat, and many waste materials.

The quantities of portland cement and water to be added and the density to which the mixture must be compacted are determined by tests. The water serves two purposes: it helps to obtain maximum compaction (density) by lubricating the soil grains, and it is necessary for cement hydration, which hardens and binds the soil into a solid mass. Soil-cement properly built contains enough water for both purposes.

portland cement. Any type of portland cement that complies with requirements of the latest ASTM, AASHO or federal specifications may be used. Types 1 and 1A, normal and air-entraining portland cements, are most commonly used.

water. The water used in soil-cement should be relatively clean and free from harmful amounts of alkalies, acids or organic matter. Water fit to drink is satisfactory. Seawater has been used satisfactorily when fresh water was unobtainable.

soil. Practically all soils and soil combinations can be hardened with portland cement. They do not need to be well-graded "aggregates" since stability is attained primarily through the hydration of cement and not by cohesion and internal friction of the materials. The general suitability of soils for soil-cement can be judged before they are tested, on the basis of their gradation and their position in the soil profile.

GRADATION. On the basis of gradation, soils for soil-cement construction can be divided into three broad groups:

1. Sandy and gravelly soils with about 10 to 35 per cent silt and clay combined have the most favorable characteristics and generally require the least amount of cement for adequate hardening. Glacial and water-deposited sands and gravels, crusher-run limestone, caliche, limerock and almost all granular materials work well, if they contain 55 per cent or more material passing the No. 4 sieve. Exceptionally well-graded materials may contain up to 65 per cent gravel retained on the No. 4 sieve and have sufficient fine material for adequate binding. These soils are readily pulverized, easily mixed and can be used under a wide range of weather conditions.

2. Sandy soils deficient in fines, such as some beach sands, glacial and wind-blown sands, make good soil-cement though the amount of cement needed for adequate hardening usually is slightly greater than with the soils in Group 1. Because of poor gradation and absence of fines in these sands, construction equipment may have difficulty in obtaining traction. Traction can be vastly improved by keeping the sand wet and by using track-type equipment. These soils are likely to be "tender" and to require care during final packing and finishing so that a smooth, dense surface may be obtained.

3. Silty and clayey soils make satisfactory soil-cement but those containing high clay contents are harder to pulverize. Generally, the more clayey the soil, the higher the cement content required to harden it adequately. Construction with these soils is more dependent on weather conditions. If the soil can be pulverized, it is not too heavy-textured for use in soil-cement.

THE SOIL PROFILE. A soil profile is a vertical cross-section of the earth's surface that exposes the different soil horizons or layers. Each soil horizon is generally of a different gradation (texture), structure and color. Color indicates the soil's chemical make-up. In some instances, the gradation of the soil is secondary to chemical make-up insofar as the soil's reaction with portland cement is concerned. For instance, a red soil indicates the presence of iron and generally reacts exceptionally well with cement. Conversely, a black farmland soil may react rather poorly with cement because of the presence of organic material.

Some surface sandy soils react poorly with cement, are slow hardening and require exceptionally high cement factors. Two alternative corrective measures may be considered: (1) replacing or blanketing the poorly reacting sand with a normally reacting soil; or (2) adding to the sandy soil a small percentage of calcium chloride, a friable silty or clayey soil, or a calcareous material such as limestone screenings. Sodium chloride or seawater may be effective also.*

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*Additional details are given in the Portland Cement Association publications, *Soil-Cement Laboratory Handbook* and *Effect of Soil and Calcium Chloride Admixtures on Soil-Cement Mixtures,* free on request only in the United States and Canada. The latter is also in Highway Research Board *Proceedings of the Twenty-third Annual Meeting,* Vol. 23, 1943, pages 497-529.

Fig. 3. Almost all soils can be hardened with portland cement. Note the very thin, dark-colored surface soil (A° horizon) underlain by a light-grey leached soil (A horizon), a dark soil layer (B horizon) and a lighter soil (C horizon). ***(Courtesy U.S. Department of Agriculture.)***

Soils formed from similar parent material and under the same climatic conditions, topography, drainage and vegetation are similar. They have the same soil profile wherever they are found. These soils have been identified by soil series by the U.S. Department of Agriculture. Studies have shown that a definite soil series and horizon will require the same amount of cement wherever it is found.* Many areas have been surveyed and mapped by the use of this classification system, and the maps and accompanying reports are a valuable aid in soil survey work.

More detailed information on soil surveying, sampling and testing is given in *PCA Soil Primer.***

use of old roadway material. The materials usually found in old gravel or stone roadways make excellent soil-cement. They generally are friable, they mix easily and require only a minimum amount of cement. Frequently the old

*L. D. Hicks, "Use of Agricultural Soil Maps in Making Soil Surveys." *Engineering Use of Agricultural Soil Maps,* Highway Research Bulletin No. 22, 1949, pages 108-116. Also, J. A. Leadabrand, L. T. Norling and A. C. Hurless, "Soil Series as a Basis for Determining Cement Requirements for Soil-Cement Construction," a paper presented at the Thirty-Fifth Annual Meeting of the Highway Research Board, January 17-20, 1956.

**Available free on request only in the United States and Canada from Portland Cement Association.

Fig. 4. Old, failing granular-base roads and streets can be salvaged and strengthened by the addition of relatively small quantities of portland cement. Often the old bituminous mat is scarified, pulverized and mixed with the old base material, and then processed.

mat, if present, can be salvaged or can be pulverized and mixed with the old base-course material for processing with cement. See Chapter 7 for further details.

use of borrow soils. From a construction or cost standpoint, it is sometimes advantageous to use a selected borrow soil instead of the soil in place. The existing soil or the soils encountered in cut sections may have a very high clay content and require a relatively high cement factor. Also, considerable effort may be required to pulverize these soils properly. Deposits of friable or granular soils that require much less cement and very little pulverizing can often be found nearby and can be used to blanket the existing soil or can be combined with it. Selective grading often is used to place the most favorable soils in the top of the grade. Comparative cost estimates will indicate the most economical soils to use.

Fig. 5. Nearby borrow materials are sometimes used instead of in-place soils.

cement content

Before construction starts, the soils that occur on the project should be identified and representative samples of each soil type should be forwarded to the laboratory for determination of the quantity of cement required. Methods of soil identification and classification as well as methods of making soil surveys and taking samples are given in *PCA Soil Primer.*

Table 1 gives the normal range of cement requirements for soils of the various AASHO soil groups. Table 2 gives average cement requirements for a number of miscellaneous materials and special types of soils. Preliminary estimates of cement requirements may be used for rough cost estimating and then confirmed or revised as laboratory test results become available. A résumé of soil-cement laboratory tests is given in Appendix A.

A proper cement content is the first requisite for soil-cement construction. In the discussions that follow, it is assumed that cement factors and boundaries of the various soils have been determined for the area to be constructed.

moisture content

The amount of water to be added depends on the moisture present in the raw soil and on the optimum moisture content of the soil-cement mixture, which varies with the texture of the soil. Soil-cement that has been mixed and is ready for com-

TABLE 1. normal range of cement requirements for B and C horizon soils [a]

AASHO SOIL GROUP	Per cent by vol.	Per cent by wt.
A-1-a	5-7	3-5
A-1-b	7-9	5-8
A-2-4, A-2-5, A-2-6, A-2-7	7-10	5-9
A-3	8-12	7-11
A-4	8-12	7-12
A-5	8-12	8-13
A-6	10-14	9-15
A-7	10-14	10-16

[a] "A" horizon soils may contain organic or other material detrimental to cement reaction and may require higher cement factors. For dark grey to grey A horizon soils, increase the above cement contents four percentage points; for black A horizon soils, six percentage points.

TABLE 2. average cement requirements of miscellaneous materials

MATERIAL	Per cent by vol.	Per cent by wt.
Caliche	8	7
Chat	8	7
Chert	9	8
Cinders	8	8
Limestone screenings	7	5
Marl	11	11
Red dog	9	8
Scoria containing plus No. 4 material	12	11
Scoria (minus No. 4 material only)	8	7
Shale or disintegrated shale	11	10
Shell soils	8	7
Slag (air-cooled)	9	7
Slag (water-cooled)	10	12

paction must be near its optimum moisture content. Optimum moisure is determined by test, AASHO Designation: T 134, "Standard Method of Test for Moisture-Density Relations of Soil-Cement Mixtures." (See Appendix B for details.)

Soil-cement at optimum moisture is neither mushy nor dry but contains sufficient moisture to make a firm cast when it is squeezed in the hand: water cannot be squeezed out of the mixture and little moisture will appear on the hand. With

Fig. 6. The hand-squeeze test is often used to judge the moisture content of soils and soil-cement mixtures.

a little experience the correct amount of moisture can be determined within practical limits by feel. A slight excess of moisture is better than not enough. From a practical standpoint, the highest moisture content should be maintained that permits packing and finishing without surface checking, "shoving," rutting or displacement during compacting and finishing operations.

Sandy soil-cement mixtures require approximately 5 gal. of water per sq.yd. for a 6-in. compacted thickness. Silty and clayey soil-cement mixtures require about 7 gal. per sq.yd. Losses by evaporation may amount to 2 or more gal. per sq.yd. Appendix B gives details of estimating water requirements.

construction

In soil-cement construction the objective is to mix pulverized soil and cement thoroughly in correct proportions with sufficient moisture to permit maximum compaction. Construction methods are simple and follow a definite procedure:

A. Initial preparation
   1. Shape the road to crown and grade.
   2. If necessary, scarify, pulverize and prewet the soil.
   3. Reshape to crown and even grade.

B. Processing
   1. Spread portland cement.
   2. Mix and apply water.
   3. Compact.
   4. Finish.
   5. Cure.

During grading operations all soft subgrade areas, springs and frost-heave areas should be located and corrected. The grade should be free of stumps and other debris. The roadway should be shaped to approximate crown and grade.

Most soil-cement is built from soils that require little or no pulverizing. If pulverization is required, it is usually done the day before actual processing. Processing operations are continuous and are completed the same working day.

types of mixing equipment

Soil-cement and water can be mixed by any of several types of equipment:

A. Traveling mixing machines
   1. Windrow type
   2. Flat type
   3. Multiple-pass rotary mixers

B. Stationary mixing plants
   1. Batch type
   2. Continuous-flow type

Whatever type of mixing equipment is used, the general principles and objectives are the same. During actual construction, two or more of the construction operations may be progressing at the same time. Some traveling mixing machines, for instance, combine two or more of the construction operations. The use of traveling mixing machines and large rotary mixers is common today. On projects that involve borrow soils, stationary mixing plants are sometimes used. Plows, discs and cultivators are rarely used today. Modern mechanical mixers are very efficient and give high daily productions with low construction costs.

Construction operations are described in more detail in subsequent chapters.

Fig. 7. A flat-type traveling mixing machine processes soil-cement in place.

Fig. 8. Another flat-type traveling mixing machine processes soil-cement in place.

Fig. 9. Multiple-pass rotary mixer processes soil-cement in place.

Fig. 10. This traveling mixing machine processes soil-cement in windrows.

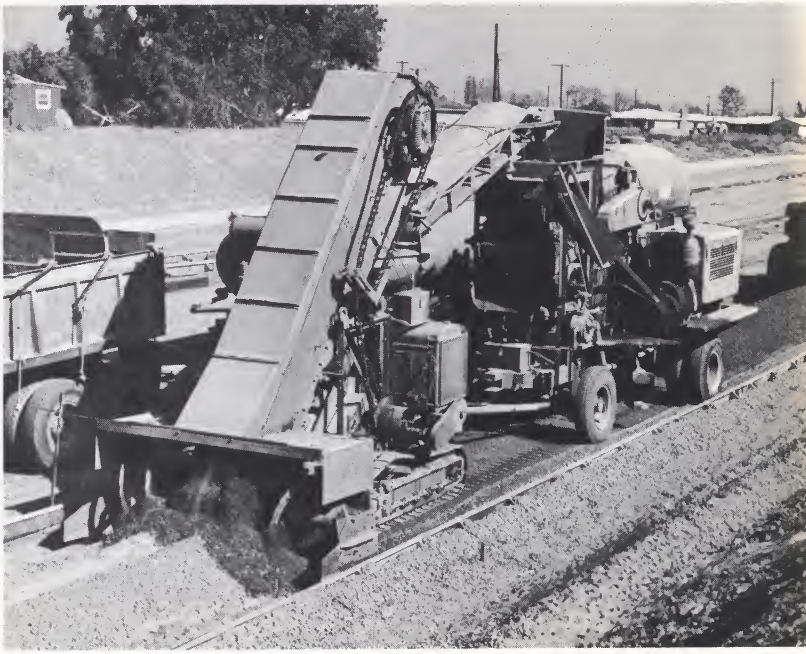

Fig. 11. A second windrow-type traveling mixing machine.

Fig. 12. A third windrow-type traveling mixing machine.

Fig. 13. A fourth windrow-type traveling mixing machine.

Fig. 14. A stationary mixing plant is sometimes used for mixing soil-cement.

fundamental control factors and inspection

The purpose of field control and inspection is to insure that the results as set out in the plans and specifications are obtained. In soil-cement construction there are three major control factors:

1. Proper cement content.
2. Proper moisture content.
3. Adequate compaction.

In addition, a thorough mix of pulverized soil and cement must be obtained. The freshly compacted and finished soil-cement must be adequately cured to permit the cement to hydrate. Competent inspection is recommended. Details of field control and inspection are given in Appendix B.

curing

Soil-cement as compacted and finished contains sufficient moisture for adequate cement hydration. A moisture-retaining cover is placed over the soil-cement soon after completion to retain this moisture and permit the cement to hydrate. In recent years most soil-cement has been cured with bituminous material, but other materials such as waterproof paper, or moist straw or dirt are entirely satisfactory.

The types of bituminous materials most commonly used are RC-2, MC-3, RT-5 and asphaltic emulsions.* Rate of application varies from 0.15 to 0.30 gal. per

*A. W. Maner, "Curing of Soil-Cement Bases." Highway Research Board *Proceedings of the Thirty-first Annual Meeting,* Vol. 31, 1952, pages 540-558. Also, *Prevention of Moisture Loss in Soil-Cement with Bituminous Materials.* Highway Research Board Research Report No. 8-F, 1949.

Fig. 15. Proper curing is essential to the hardening of soil-cement. A thin covering of bituminous material is being used to cure this soil-cement base.

sq.yd. At the time of application the soil-cement surface should be free of all dry, loose and extraneous material. Bituminous cover materials are applied to a very moist soil-cement surface and in most cases water is applied immediately ahead of the bituminous application. When traffic is to be maintained, the bituminous material is sanded to prevent its pickup by traffic.

Soon after construction, transverse shrinkage cracking occurs in the soil-cement base course. Such shrinkage cracking is a natural characteristic of soil-cement and does not affect the performance of the base course detrimentally. It is evidence that cement hydration is producing a hardened base course. Most cracks appear the first few days after construction although additional cracks may appear during the first few months.

bituminous surface

A bituminous surface should be placed on the completed soil-cement base course as soon as practical. Although it is not unusual for several weeks to elapse between the completion of the soil-cement and placement of the wearing course, it may be placed immediately if necessary.

The type and thickness of surfacing depend on traffic volume, availability of materials, cost and local practices. In general the thickness of the wearing course necessary on a rigid soil-cement base course will be less than that required on a granular-type base. A common type of wearing course for lightly traveled roads and streets is a double surface treatment about ¾ in. in thickness. As traffic volumes increase, thicker, higher-quality surfacings are warranted. A common type of wearing course for airports having much traffic is a 1½-in. plant mix.

Local experience and practice will dictate the specific details of construction. Good construction practices such as thorough cleaning of the exposed surface should always be followed when the surfacing is placed.

There are special uses of soil-cement where bituminous surfaces are not justified. Coal storage areas are an example.

traffic

Traffic in small volume can be handled through the construction area. If side ditches or shoulders are flat, traffic can be diverted to these areas. In extreme cases, where traffic volume is large and detours are not feasible, half-width construction may be employed, but this is not the best practice since a longitudinal construction joint must be built. Loads of less magnitude than that of the equipment used in building the soil-cement will not harm the freshly constructed base provided the subgrade is stable. Traffic should be controlled since high-speed traffic may mar the "green" surface. If traffic is to be maintained, provisions should be made to keep the curing material in place.

soil-cement thickness

Most soil-cement base courses are constructed 6 in. thick but they may be reduced to 5 in. if the subgrade is very stable. For very light traffic, a 4-in. thickness may be adequate. For high traffic volumes, thickness as great as 8 in. may be warranted and can be constructed in one layer if suitable equipment is available. For a thickness greater than 8 in. the base course must be built in multiple layers.

Soil-cement has a substantially greater bearing value than the best granular materials. Some state highway design methods measure and take into considera-

tion the quality and strength of different base-course materials.* When this is done, thinner sections of soil-cement are often used for the same traffic and subgrade conditions at a saving in construction costs.

TABLE 3. plate-bearing test results on various types of base courses

SUBGRADE BEARING VALUE	BASE-COURSE TYPE	BEARING VALUE—$k^{(a)}$
k-125	6-in. soil-cement	535
k-125	8-in. compacted gravel	355
k-400	6-in. soil-cement	1012
k-376	5½-in. macadam, 2-in. bituminous surface	626
k-190	6-in. soil-cement, 2-in. bituminous surface	400
k-220	6-in. emulsion stabilized, 2-in. bituminous surface	229
——	6-in. soil-cement	940
——	8-in. sand-clay, bituminous seal	520
CBR-30	6-in. soil-cement, bituminous seal	424
CBR-17	8-in. bituminous stabilized, 2-in. bituminous surface	275

(a) Psi per in., 30-in. plate at 0.2-in. deflection.

There are two general types of road cross-section—trench and feather-edge. Both can be built satisfactorily with soil-cement. In trench-type construction the shoulder material gives lateral support to the soil-cement mixture during compaction. With the feather-edge type of construction, the edges are compacted first to provide some edge stability while the remaining portion is being compacted. The edge slope should not be steeper than 2:1 to facilitate shaping and compacting. Shoulder material is placed after the soil-cement has been finished. For the same bituminous surface width, a greater width of base course is required in the feather-edge design.

Some details of design are given in "Thickness of Flexible Pavements," *Current Road Problems* No. 8-R, Highway Research Board, November 1949.

cost estimates and specifications

Information sheets are available free only in the United States and Canada from Portland Cement Association as an aid in preparing cost estimates and job specifications. They are *Form for Use in Preparing an Approximate Cost Estimate for Soil-Cement Construction* and *Suggested Specifications for Construction of a Soil-Cement Base Course.*

special construction items—weather

Wet weather can be a construction hazard. Although during the normal summer construction months there is no great danger, certain ordinary precautions should

*F. N. Hveem and R. M. Carmany, "The Factors Underlying the Rational Design of Pavements." Highway Research Board *Proceedings of the Twenty-eighth Annual Meeting,* Vol. 28, 1948, pages 101-136. Also, State Highway Commission of Kansas, *Design of Flexible Pavements Using the Triaxial Compression Test.* Highway Research Board Bulletin No. 8, 1947.

be taken. For example, any loose or pulverized soil should be carefully graded so it will shed water, and low places in the grade where water may accumulate should be trenched so that they will drain freely. Attention to a few simple precautions such as these greatly reduces the possibility of serious damage.

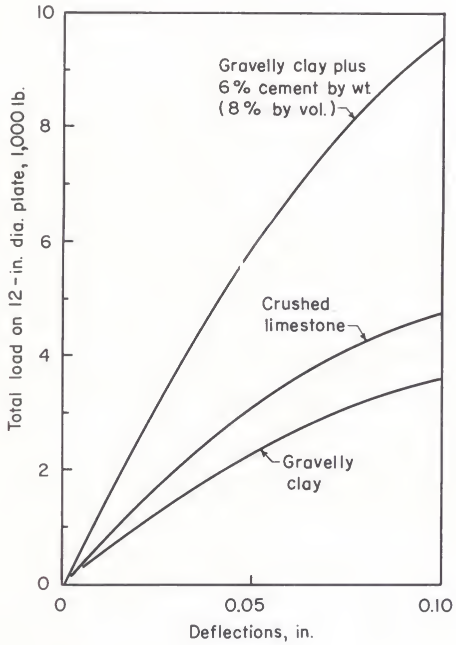

Fig. 16. Plate-bearing tests show that the total load required to produce 0.1-in. deflection on this soil-cement is about twice that required to produce the same deflection on crushed limestone and 2½ times that for a plastic gravelly clay.

rainfall. The inexperienced contractor and engineer may believe that rain is a most serious construction hazard but, as shown by the construction of millions of square yards of soil-cement in all climates, it is unlikely that rainfall during actual construction will be a problem to the experienced engineer. Usually construction requires the addition of water equivalent to 1 to 1½ in. of rain.

A light drizzle causes no harm. If rain falls during cement-spreading operations, spreading is stopped and the cement already spread is quickly cut into the soil mass. A heavy rainfall that occurs after most of the water has already been added may be serious. Generally the best procedure is to obtain rapid compaction by using every piece of equipment so that the section will be packed and shaped before too much damage results from the rain. In such instances it may be necessary to complete final blading later; any material bladed from the surface then is wasted.

After the mixture has been packed and finished, rain will do no harm.

wet soil. Excessively wet soil is difficult to mix and pulverize. Experience has shown that cement can be mixed with sandy soils when the moisture content is as high as two percentage points above optimum. For clayey soils the moisture content should be at least three percentage points below optimum for efficient mixing. Only rarely is it necessary to dry out a soil by aeration, but if necessary, efficient aeration can be obtained by using heavy-duty field cultivators and rotary mixers operated with the hood open.

The maintenance of good crown and surface grade to permit rapid runoff of surface water before soil-cement processing is the best insurance against excessive amounts of wet soil.

soft subgrade. Proper compaction is one of the fundamental requirements of soil-cement construction. If the subgrade is soft and cannot properly support the compaction equipment, adequate compaction will not be obtained. Therefore, soft areas should be located and corrected before processing begins.

Shallow, soft subgrade areas are usually due to poor maintenance of the grade prior to soil-cement processing. Such areas can usually be stabilized by aerating and recompacting the soil. Large, deep, soft subgrade areas may be "subprocessed" with soil-cement. In subprocessing, the top layer of soil is bladed aside and the bottom layer is mixed with cement and compacted. The drying action of the cement and its hydration for two or three days will harden the area sufficiently that the top layer of soil can be replaced and processed in the usual manner.

Springs, seepage areas and differential frost-heave areas should be located and adequately drained.

In certain instances soft subgrades will not show up until rolling has been partially completed. In cases where minor distress is indicated by cracking and shoving, the rollers are removed and final rolling is done with empty trucks or a lightweight roller.

cold weather. Soil-cement, like other cement-using products, hardens as the cement hydrates. Since cement hydration practically ceases when temperatures are near or below freezing, soil-cement should not be placed when the temperature is 40 deg. F. or below. Moreover, it should be protected to prevent its freezing for a period of 7 days after placement by a suitable covering of hay, straw or other protective material.

chapter 2 ROAD CONSTRUCTION

Soil-cement road construction involves two general operations—(1) preparation and (2) processing—which can be divided into definite construction steps. Minor variations in the steps, dictated by the type of mixing equipment used, are discussed in this chapter in Examples 1 through 4. Regardless of the equipment and methods used, it is essential to have an adequately compacted, thorough mixture of pulverized soil that contains the proper amount of cement and moisture.

preparation

Before construction starts, the crown and grade of the roadway should be checked and any fine grading should be completed. Since there is little longitudinal displacement of soil during processing, the grade at start of construction will determine the final grade to a major extent. If borrow soil is to be used the subgrade should be compacted and shaped to proper crown and grade before the borrow is placed.

To avoid later, costly delays all equipment should be carefully checked to insure that it is in good operating condition and conforms to the construction requirements of the job.

Guide stakes should be set to control the width of treatment and to guide the operators during construction.

Arrangements should be made to receive, handle and spread cement and water efficiently. The number of cement and water trucks that will be required depends on length of haul, condition of haul roads and anticipated rate of production.

Fig. 17. Soils can be pulverized more easily if they contain the proper moisture content and if proper equipment is used.

The limits of the different soils and their corresponding cement requirements should be established by the project engineer.

scarification, pulverization and prewetting. The first construction operation is to scarify, pulverize and prewet the soil. This operation may or may not be required, depending on the soil type and the mixing equipment. Most soil-cement is constructed with friable soils that require little or no scarification or pulverization. Silty and clayey soils only may require extra effort to pulverize them, particularly if they are too dry or too wet. There are two keys to easier pulverization:

1. Proper moisture control.
2. Proper equipment.

Soils that are difficult to pulverize when dry and brittle can be broken down readily if water is added and allowed to soak in, whereas sticky soils can be pulverized more easily when they are dried out a little. Proper equipment will help to reduce pulverization work to a minimum. Pulverizers, rotary mixers, disc harrows and rollers are commonly used.

Most specifications require that the soil be pulverized sufficiently that at the time of compaction 100 per cent of the soil-cement mixture will pass a 1-in. sieve and that a minimum of 80 per cent will pass a No. 4 sieve, exclusive of any gravel or stone. The final pulverization test is made at the conclusion of mixing operations.

Prewetting by adding moisture before cement is applied often helps in scarifying and pulverizing the soil and often saves time during actual processing operations (see page 36 for further discussion).

placing borrow soil. Most soil-cement is constructed with the materials already in the roadway. However, when borrow soil is specified, it should be distributed evenly on an accurately graded, well-compacted roadway. It may be placed by weight or by volume as required by the specifications.

Fig. 18. Belt conveyor is used to unload bulk portland cement from a hopper-bottom railroad car.

processing

Four examples are given to illustrate soil-cement processing with various types of equipment. Typical construction steps and equipment requirements are listed along with a discussion of construction details.

handling and spreading portland cement. Cement may be spread in required amounts by mechanical bulk cement spreaders or by hand from bags. Bulk cement is used on most jobs; bag cement is sometimes used on small jobs.

There are many methods of handling cement. Those most commonly used are shown in the accompanying photographs.

Fig. 19. Screw conveyor is used here to unload bulk portland cement from a transport truck.

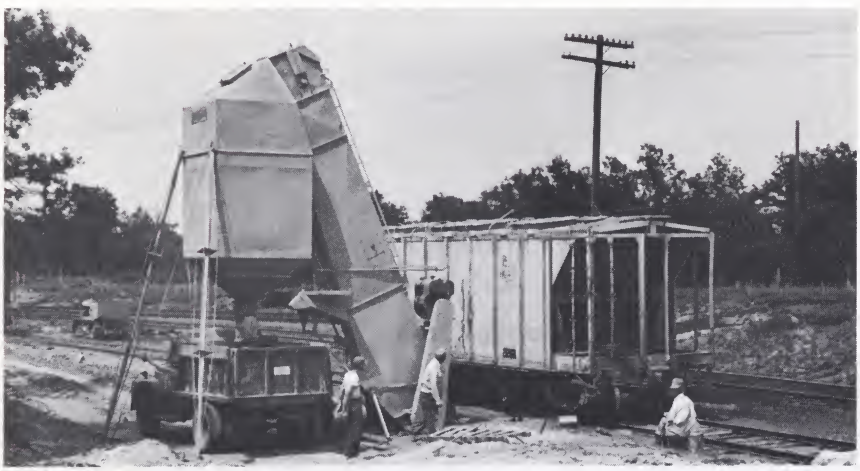

Fig. 20. Combination screw and bucket conveyors are available for unloading bulk cement.

Bulk cement is shipped to the nearest railroad siding in enclosed hopper cars or boxcars or is trucked to the job site in bulk transport trucks. Poles, compressed air or vibrators are used to loosen the cement in hopper cars during unloading. The cement is transferred to job cement trucks, which are enclosed or fitted with canvas covers. Either a screw or belt conveyor or a cement hog is used to transfer the cement. Truckloads of cement are weighed on portable platform scales or at a nearby grain or coal scale. On the job a mechanical cement spreader is attached to the job truck and as the truck moves forward, cement flows through the spreader, which regulates the quantity of cement spread on the prepared soil. Bulk-cement spreaders should be operated at a constant slow rate of speed to obtain a uniform cement spread.

Fig. 21. Unloading ramps can sometimes be used to transfer bulk portland cement from bulk transport trucks directly to job trucks.

Fig. 22. Portable platform scales are commonly used to weigh truckloads of cement. Local grain or coal scales are often used also.

Fig. 23. Mechanical cement spreaders attached to job trucks are used to distribute bulk portland cement.

Fig. 24. Flat-type mechanical spreaders operated at a constant slow rate of speed deposit portland cement in a thin layer over the soil.

Fig. 25. Windrow-type mechanical spreaders are used to place the cement in the top of a windrow of soil.

Fig. 26. Bags of portland cement are spotted both transversely and longitudinally at regular, predetermined intervals. Bags are opened and cement is dumped to form a transverse windrow of cement.

Cement spreaders are of two general types: those that spread cement over the soil 6 to 10 ft. wide, and those that are designed to deposit cement on top of a windrow of soil.

With hand spreading, some simple but exact method for properly spotting the bags is necessary. Bags can be spotted correctly by flags or markers fastened to chains at proper intervals to mark transverse and longitudinal rows. Spacing of the bags should be practically square and such that the proper percentage of cement will be added. When the bags are opened, cement is dumped so that it forms a fairly uniform transverse windrow across the area being processed. A drag should make at least two round trips over the area to spread the cement uniformly. A spike-tooth harrow, a nail drag, a length of chain-link fencing or the tailgate of a rotary mixer can be used for evening the spread of cement. (Details of calculating cement quantities and methods used in checking the amount of cement spread are given in Appendix B.)

Soils that contain excessive amounts of moisture will not mix readily with cement. Sandy soils can be mixed with a moisture content at optimum or slightly above, while clayey soils should have a moisture content slightly below optimum for efficient mixing. If the soil is excessively wet it should be aerated and dried before cement is applied.

Fig. 27. Windrows of portland cement are spread longitudinally by a spiketooth harrow or other implement.

In the following examples, soil-cement processing with various types of equipment is discussed only through mixing operations.

example 1. construction with windrow-type traveling mixing machine

CONSTRUCTION STEPS

A. Preparation

With in-place soil

1. Shape roadway to crown and grade.
2. Scarify roadway soil.
3. Pulverize soil if necessary.
4. Windrow soil and even windrow.

With borrow soil

1. Shape subgrade to crown and grade.
2. Compact subgrade.
3. Place borrow soil.
4. Windrow soil and even windrow.

B. Soil-cement processing

1. Spread portland cement.
2. Mix and apply water.
3. Spread mixed windrow.
4. Compact.
5. Finish.
6. Cure.

TYPICAL EQUIPMENT REQUIREMENTS

For preparation:

1 pulverizer, if required
1 motor grader with scarifier
1 windrow evener or spreader box

For handling bulk cement:

1 cement conveyor
1 cement tanker
1 portable truck scale
1 windrow-type mechanical cement spreader

For mixing and water application:

1 windrow-type traveling mixing machine with motive power
1 water pump at source
2 or more water supply trucks as needed
1 motor grader for spreading mixed windrow

For compaction: See page 41.
For finishing: See page 44.
For curing: See page 18.

DISCUSSION. Windrow-type traveling mixing machines will pulverize friable soils. Other soils may need preliminary pulverizing to meet specification requirements. This is usually done before the soil is placed in the windrow for processing. The prepared soil is bladed into a windrow by a motor grader. An evener is pulled along the windrow to make it uniform in cross-section. Nonuniform windrows cause variations in cement content, moisture content and pavement thickness.

Fig. 28. Windrows should be spread evenly.

The number and size of windrows needed depend on the width and depth of treatment and on the capacity of the machine used for mixing; usually two or three windrows are required.

Cement is applied to the top of the prepared soil windrow either in bulk or by the bag. The mixing machine picks up the soil and cement, which are dry-mixed by the first few paddles in the mixing drum. At this point water is added through spray nozzles and the remaining paddles complete the mixing. The mixed soil-cement is deposited in a windrow and a motor grader is used to spread the mixture. If a sheepsfoot roller is to be used for compaction, the mixture is loosened with a cultivator. The material is then ready for compaction. After mixing has progressed 350 to 500 ft. along one windrow, the machine backs up and processes the other windrow for 700 to 1,000 ft., if two windrows are being used.

Cement spread is kept just ahead of mixing operations. Water is supplied by tank trucks. The installation of a water tank on the mixer permits continuous operation while tank trucks are being changed. As soon as the mixer is out of the way, the mixed windrow is spread and compaction is begun on this portion of the roadway. As the mixer progresses down the second windrow the mixed material is spread and then immediately compacted. The entire roadway width is finished in one operation.

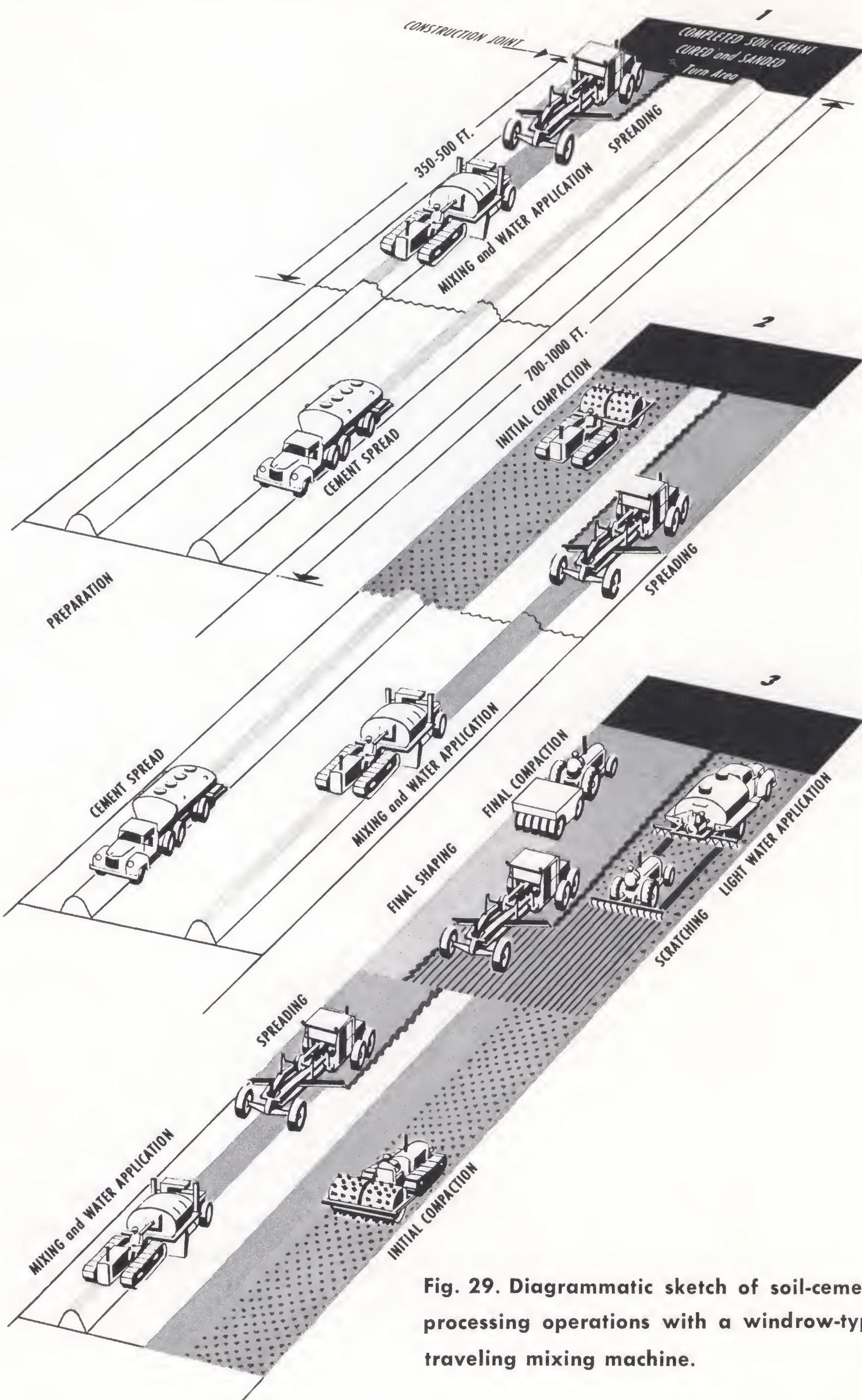

Fig. 29. Diagrammatic sketch of soil-cement processing operations with a windrow-type traveling mixing machine.

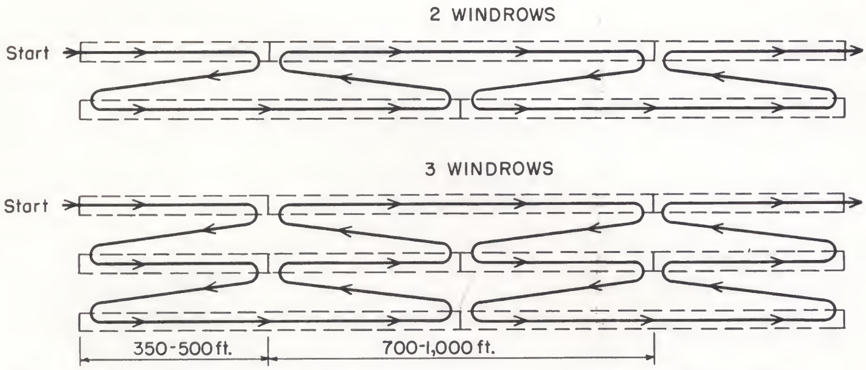

Fig. 30. Plans for processing with windrow-type traveling mixing machine.

example 2. construction with flat-type traveling mixing machine

CONSTRUCTION STEPS

A. Preparation

With in-place soil

1. Shape roadway to crown and grade.
2. Loosen soil to design depth when necessary and reshape.

With borrow soil

1. Shape subgrade to crown and grade.
2. Compact subgrade.
3. Place borrow soil.
4. Shape borrow soil.

B. Soil-cement processing

1. Spread portland cement.
2. Mix and apply water.
3. Compact.
4. Finish.
5. Cure.

TYPICAL EQUIPMENT REQUIREMENTS

For preparation:

1 motor grader

For handling bulk cement:

1 cement conveyor
2 or more cement trucks as required
1 portable truck scale
1 mechanical cement spreader—6 to 10 ft. wide

For mixing and water application:

1 flat-type traveling mixing machine
1 water pump at source
2 or more water supply trucks as needed

For compaction: See page 41.
For finishing: See page 44.
For curing: See page 18.

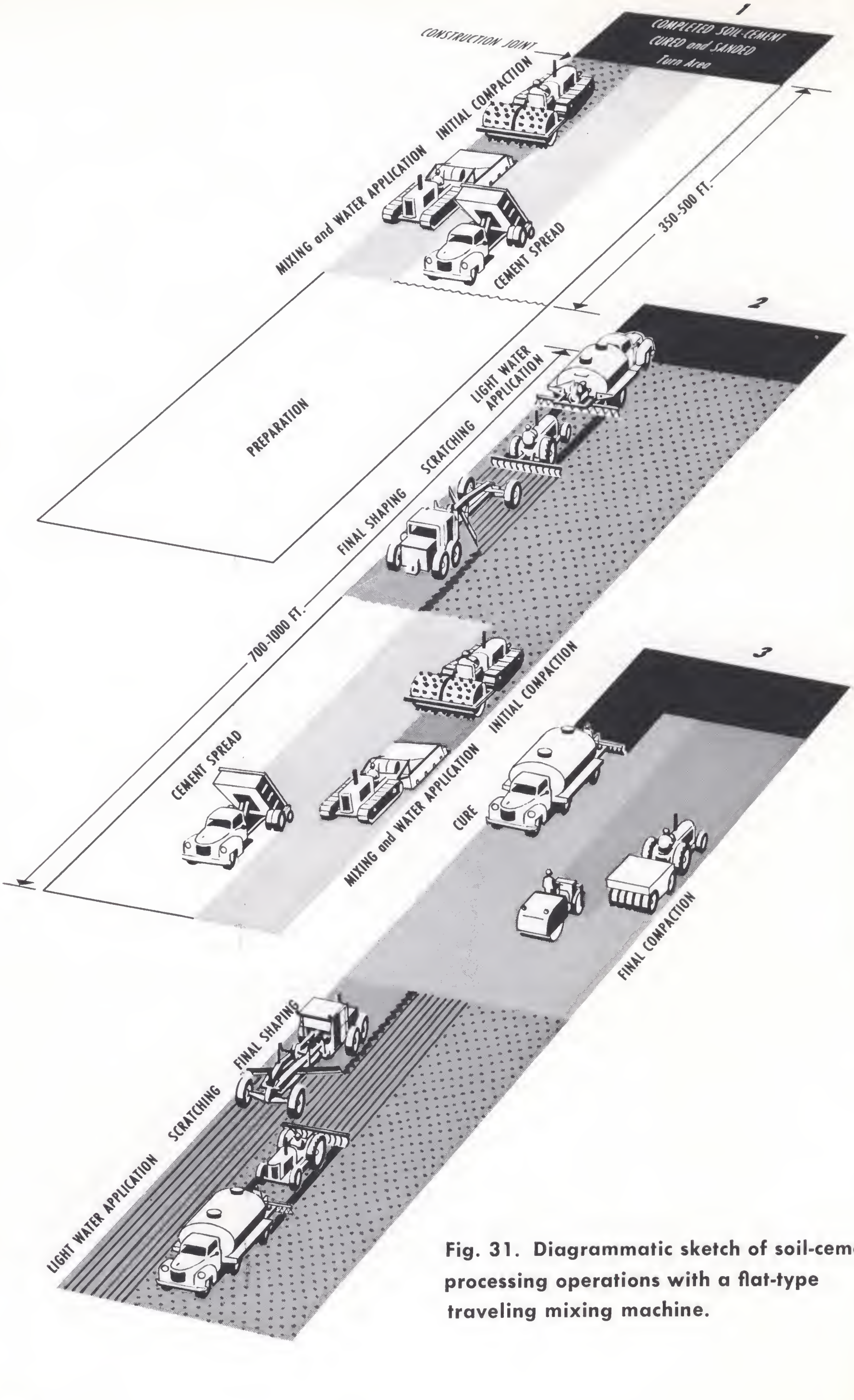

Fig. 31. Diagrammatic sketch of soil-cement processing operations with a flat-type traveling mixing machine.

DISCUSSION. Since most flat-type traveling mixing machines have a high-speed pulverizing rotor, preliminary pulverization usually is unnecessary. The only preparation required is shaping the soil to approximate crown and grade. Occasionally an old roadbed may be extremely hard and dense and in such cases prewetting and scarification will facilitate processing.

Processing is done in lanes 350 to 500 ft. long with a width equal to that of the machine. Cement is spread over the soil in front of the mixing machine. Either bulk cement or bag cement can be used. Cement spreading should be completed in the first working lane and underway in the second lane before mixing operations are started. This assures a full-width cement spread without a gap between lanes; also, cement-spreading equipment is out of the way of mixing equipment. The machine picks up the soil and cement and mixes it in place. The first rotors in the mixing machine pulverize the soil and dry-mix soil and cement. Water is measured through a meter and injected into the mix through a spray bar in the mixing chamber. The remaining rotors mix the soil, cement and water and the mixed material is left flat on the roadway for immediate compaction. Water is supplied to the mixer by tank trucks. A small exchange water tank on the machine permits continuous operation while water trucks are being changed. After compaction the roadway is finished full width in one operation.

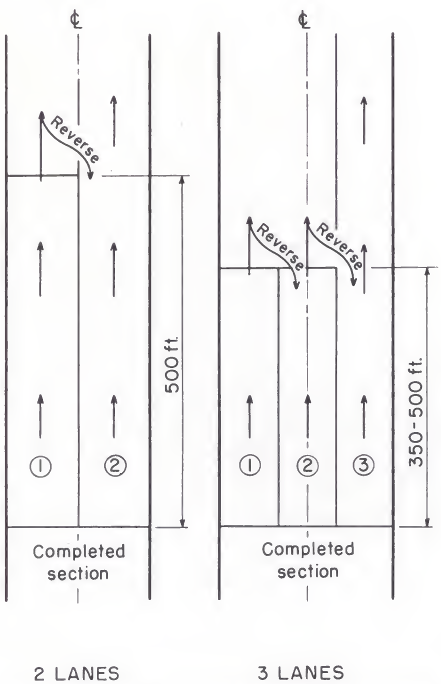

Fig. 32. Plans for processing with flat-type traveling mixing machine.

example 3. construction with multiple-pass rotary mixer

CONSTRUCTION STEPS

A. Preparation

With in-place soil

1. Shape roadway to crown and grade.
2. Scarify roadway soil.
3. Pulverize soil, if necessary.
4. Prewet soil as needed.
5. Shape prepared soil.

With borrow soil

1. Shape subgrade to crown and grade.
2. Compact subgrade.
3. Place borrow soil.
4. Shape borrow soil.

B. Soil-cement processing

1. Spread portland cement.
2. Mix, apply water and mix.
3. Compact.
4. Finish.
5. Cure.

TYPICAL EQUIPMENT REQUIREMENTS

For preparation:

1 motor grader with scarifier
x rotary mixers for pulverizing, if necessary
1 water truck with pressure spray bar for prewetting as needed

For handling bulk cement:

1 cement conveyor
2 or more cement trucks as required
1 portable truck scale
1 mechanical cement spreader—6 to 10 ft. wide

For mixing and water application:

x rotary mixers—same as above
1 water pump at source
2 or more water pressure distributors or water supply trucks as needed

For compaction: See page 41.

For finishing: See page 44.

For curing: See page 18.

DISCUSSION. Soil-cement construction with rotary mixers is slightly different from the preceding examples in that it is a multiple-pass operation. The basic principles and objectives are the same, however.

Shaping the roadway, scarification and pulverization are the first steps of preparation, as described on pages 23 and 24. Since most rotary mixers were not designed to scarify, usually the soils must be loosened with a scarifier. Prewetting the soil during scarification and pulverization is common practice. Applying water at this stage of construction saves time during actual processing operations because most of the required water has already been added to the soil when cement is spread. In very granular soils, prewetting prevents cement from sifting to the bottom of the mix by causing it to adhere more readily to the sand and gravel

particles. Mixing of soil and cement is easier if the moisture content of the raw soil is two or three percentage points below optimum. But very sandy soils can be mixed even if the moisture content is one or two percentage points above optimum. Moisture should be applied uniformly during prewetting. By mixing it into the soil, evaporation losses are reduced. Because of the hazard of night rains, some prefer to do the prewetting in the early morning. After scarifying, pulverizing and prewetting, the loose, moist soil is shaped to crown and grade.

Cement is spread through a mechanical cement spreader or by the bag. Cement should not be applied in puddles of water or to soils that are extremely wet because of prewetting or rain.

Occasionally the prewet soil becomes compacted by cement-spreading equipment. In such cases, mixing may be hastened by loosening the soil again after cement is spread, usually with the scarifier on a motor grader. The scarifier teeth should be extended so that cement will flow through the teeth and not be carried forward or displaced by the scarifier frame. A cultivator may also be used.

Cement and soil are then mixed. The objective at this stage is to distribute cement throughout the soil mass. Only enough mixing is required to prevent cement balls from forming when water is applied. Complete and thorough mixing is not necessary at this stage of construction.

Next, sufficient water is applied in increments to bring the mixture to optimum moisture. Each increment is mixed with the soil and cement. Water is usually applied either by water pressure distributors or by a spray bar mounted in front of the rotor on the mixer and supplied by a water truck. After the last increment of water has been applied, mixing is continued until the soil, cement and water are thoroughly mixed throughout the full depth and width of treatment. The material is then ready for compaction and finishing.

Fig. 33. Prewetting is helpful in pulverization of dry, hard soils and often saves time during actual processing operations.

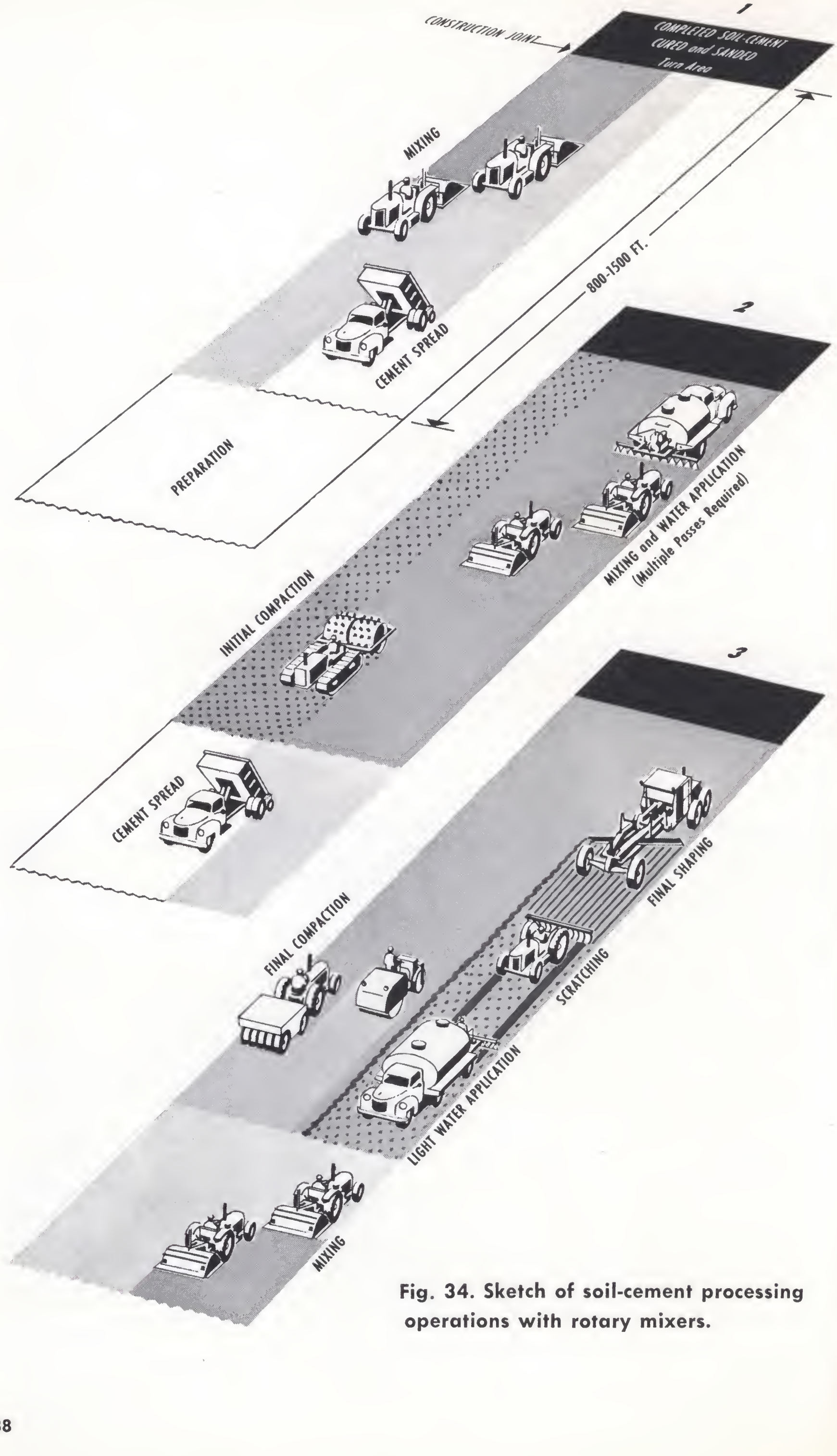

Fig. 34. Sketch of soil-cement processing operations with rotary mixers.

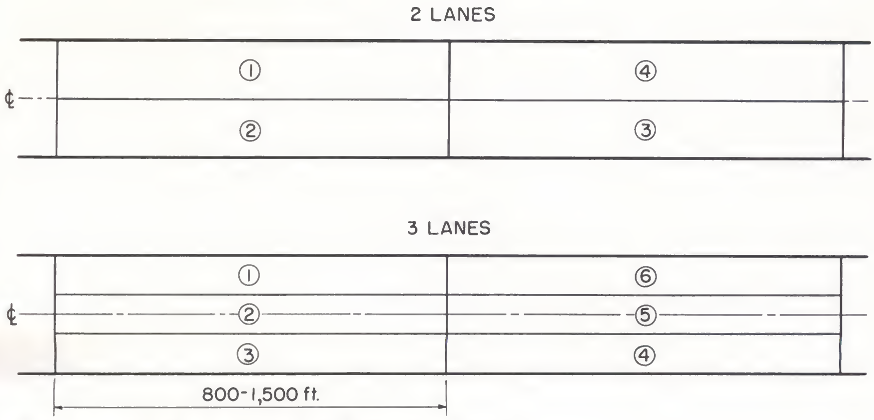

Fig. 35. Plans for processing with rotary mixers.

Fig. 36. If pulverized soil becomes partially compacted by equipment before and during cement spread, reloosening it with the scarifier on the motor grader will hasten mixing. The cement should flow through the scarifier teeth and not be carried forward by the scarifier frame.

example 4. construction with stationary mixing plant

CONSTRUCTION STEPS

A. Preparation

With borrow soil

1. Shape subgrade to crown and grade.
2. Compact subgrade.

B. Soil-cement processing

1. Mix soil, cement and water in plant.
2. Haul mixed soil-cement to roadway and spread.
3. Compact.
4. Finish.
5. Cure.

TYPICAL EQUIPMENT REQUIREMENTS

For preparation:

Motor grader

Rollers

For mixing:

1 stationary mixing plant, batch-type or continuous-flow type with facilities for storing, handling and proportioning soil, cement and water

For placing:

x haul trucks as needed

2 spreader boxes

For compaction: See page 41.

For finishing: See page 44.

For curing: See page 18.

DISCUSSION. Stationary mixing plants are sometimes used on projects involving borrow soils when the haul is not too long.

The same basic principles of thorough mixing, adequate cement content, proper moisture content and adequate compaction apply. Friable granular borrow soils are generally used because of their low cement requirements, ease in handling and mixing. If plastic soils are used they may require preliminary pulverizing to meet specification requirements.

Pugmill-type mixers, either of the batch or continuous-flow type, are best suited for this work. Facilities for efficiently storing, handling and proportioning materials must be provided at the plant. Quantities of soil, cement and water may be proportioned by volume or weight. A mixing time of 30 seconds after all materials are in the mixer is usual. However, the mixing time must be increased if complete and thorough mixing is not being obtained. To reduce evaporation losses, haul trucks should be equipped with canvas covers and haul time is usually restricted to 30 minutes. Mixed soil-cement is spread through spreader boxes. Dumping in piles and spreading with a motor grader is not good practice because it produces nonuniform densities in the spread material. The mixed soil-cement should be spread to full roadway width either by one spreader or by several spreaders operating in a staggered position across the roadway. Less preferable is the use of one piece of spreading equipment operating alternately in two or more lanes. No lane should be spread so far ahead of the adjoining lane that a time lapse of more than 25 minutes occurs between the times of placing ma-

terial in adjoining lanes at any location. Spread material should be compacted immediately.

compaction. In this chapter thus far roadway preparation and soil-cement processing through the mixing operations have been discussed.

After the mixture has been moistened to optimum and thoroughly mixed, it should be compacted to maximum density and finished immediately. Optimum moisture and maximum density are determined by the Proctor method (AASHO Designation: T 134).* Moisture lost by evaporation during compaction, as indicated by the greying of the surface, should be replaced with light applications of water.

There are numerous types of compaction equipment. Those most commonly used in soil-cement construction are sheepsfoot, pneumatic-tired or steel-wheel rollers. Many newer types of soil compaction equipment have been developed: grid-type rollers, segmented steel-wheel rollers, plate vibratory compactors, vibratory steel-wheel rollers, vibratory pneumatic-tired rollers, heavy pneumatic-tired rollers, and tampers. Plate vibrators, grid and segmented rollers have been used to compact satisfactory soil-cement made of nonplastic granular soils.

*Modified as follows: Test run on total sample, i.e., soil and gravel. Maximum size of gravel limited to ¾ in. Gravel larger than ¾ in. replaced with an equivalent weight of No. 4 to ¾-in size gravel.

Fig. 37. Plant-mixed soil-cement should be spread through spreader boxes and compacted immediately.

Fig. 38. Sheepsfoot rollers are commonly used to compact most soils.

Sheepsfoot rollers are generally used to compact all but the most granular soils. To obtain adequate compaction it is best to operate the rollers with ballast to give high unit pressures. The general rule is to use the heaviest roller that will not overstress the soil mixture and that will still "walk out" in a reasonable number of passes. Friable silty and clayey sandy soils will compact with rollers having unit pressure of 75 to 125 psi. Clayey sands, lean clays and silts that have low plasticity will pack with 100- to 200-psi rollers. Medium to heavy clays and gravelly soils require higher unit pressures—150 to 300 psi.* Eight-inch compacted thickness is about the maximum that can be compacted satisfactorily with most sheepsfoot rollers.

Pneumatic-tired rollers are used to compact very sandy soils containing little or no binder material—that is, dune or blow sand. Sand and gravel having very little or no plasticity can also be compacted satisfactorily with pneumatic-tired rollers. These rollers are usually heavily loaded and pulled with a track-type tractor equipped with street plates. A second and lighter pneumatic-tired roller pulled by a tire tractor is used for finish-rolling on almost all soils. Cohesionless sand may also be compacted with large track-type tractors with street plates. Compaction is

*"Contact Pressures and Sizes of Tamping Feet Best Suited for Compacting Different Soils with Sheepsfoot Rollers," Table 14 in *Compaction of Embankments, Subgrade, and Bases,* Highway Research Board Bulletin No. 58, 1952, page 26.

obtained by the weight and vibration of the tractor. A 6-in. compacted depth is about the maximum that can be compacted in one lift with these methods.

Twelve-ton, three-wheel steel rollers are commonly used in some areas to compact granular soils containing little or no binder material. Gravelly soils that contain up to 20 per cent material passing the No. 200 sieve and that have low plasticity are best suited for compaction with these rollers. Compacted depth of 6 or 7 in. is about the maximum thickness that can be compacted satisfactorily with this equipment.

When sheepsfoot rollers are used for initial compaction, the mixed material must be in a loose condition so that the compaction feet will penetrate to the bottom and gradually "pack out." In some instances penetration may not be obtained and a cultivator or rotary mixer may be used to loosen the mix during sheepsfooting, thus allowing the feet to penetrate. Such a procedure will also increase densities.

Occasionally during compaction and finishing a localized area may yield under the compaction equipment. This may be due to one or more of the following

Fig. 39. Pneumatic-tired rollers pulled by track-type tractors equipped with street plates are commonly used to compact cohesionless sands.

Fig. 40. Twelve-ton, three-wheel steel rollers are sometimes used to compact granular soils with low plasticity.

causes: (1) the soil-cement mix is much wetter than optimum moisture, (2) the subsoil may be wet and unstable or (3) the roller may be too heavy for the soil. If the soil-cement mix is too damp it should be aerated with a cultivator, rotary mixer or motor grader. After it has been dried to near optimum moisture it is compacted.

Some silty soils may be overcompacted. This is not usual, but the roller may be too heavy and have too high unit pressures for the soil being compacted.

For best results compaction should start immediately after the soil, cement and water have been mixed. Densities are obtained more readily, there is less water evaporation and production is increased. Most specifications require that soil-cement be compacted to within 5 lb. (some specify 95 per cent) of the maximum density as determined on a representative field sample taken from the moist mix (AASHO Designation: T 134).* Excess densities are beneficial. Details of moisture and density control are given in Appendix B.

finishing. There are several acceptable methods of finishing soil-cement. The exact procedure depends on the equipment, job conditions and soil characteristics. Regardless of the method used, the fundamental requirements of adequate compaction with not less than optimum moisture and of removal of all surface compaction planes** must be met to produce a high-quality surface. It should be smooth, dense and free of ridges or cracks. Following are outlines of several of the methods in use today. All will produce satisfactory compaction and surface finish if the fundamentals are adhered to.

---

*Modified as follows: Test run on total sample, i.e., soil and gravel. Maximum size of gravel limited to ¾ in. Gravel larger than ¾ in. replaced with an equivalent weight of No. 4 to ¾-in size gravel.

**Surface compaction planes are smooth areas left near the surface by wheels of equipment, motor-grader blade or sheepsfoot-roller feet. A thin surface layer of compacted soil-cement may not adhere properly to these areas and in time may fracture, loosen and spall. For good bond, the area must be rough and damp. A scratcher, such as a weeder, nail drag or spiketooth harrow, is used to remove potential surface compaction planes.

METHODS OF FINISHING

Method 1. Finishing procedure for most soil-cement mixtures compacted with sheepsfoot roller:

1. Remove compaction planes with weeder, nail drag or spiketooth harrow while shaping with motor grader.*†
2. Roll with pneumatic-tired roller.
3. "Scalp" with motor grader.†
4. Roll with pneumatic-tired roller.*‡

*Light application of water as needed.
†Broom drag sometimes used to level ridges.
‡Tandem steel-wheel roller is sometimes used prior to final rolling with pneumatic-tired roller.

Method 2. Finishing procedure for mixtures containing appreciable quantities of gravel and little or no plasticity and compacted with sheepsfoot roller:

1. Shape with motor grader.
2. Roll with steel-wheel roller.
3. Broom drag.
4. Roll with pneumatic-tired roller.*

*Light application of water as needed.

Method 2a. Alternate for Method 2:*

1. Shape with motor grader.†
2. Mulch and level with rotary mixer for 2-in. ± depth.
3. Roll with steel-wheel roller.
4. Roll with pneumatic-tired roller.†

*Only for very coarse granular mixtures containing appreciable quantities of gravel. Not recommended for other soil-cement mixtures.
†Light application of water as needed.

Method 3. Finishing procedure for very sandy mixtures containing little or no fines* and compacted with heavy pneumatic-tired roller pulled by track-type tractor with street plates:

1. Remove compaction planes with weeder, nail drag or spiketooth harrow while shaping with motor grader.†
2. Roll with pneumatic-tired roller and drag with broom.
3. "Scalp" with motor grader.
4. Broom drag.
5. Roll with pneumatic-tired roller.†

*Such as cohesionless dune or blow sand containing 0 to 10 per cent minus No. 200 sieve material.
†Light application of water as needed.

Method 4. Finishing procedure for coarse granular mixtures compacted with 3-wheel, 12-ton steel roller:*

1. "Scalp" high areas with motor grader.
2. Roll with pneumatic-tired roller.†

*Material must be level and approximately to crown and grade before compaction. For coarse granular mixtures (not blow sands) containing up to 20 per cent material passing the No. 200 sieve with low P.I.
†Light application of water as needed.

These are all acceptable methods of finishing soil-cement. The objective is to produce a smooth, dense, moist surface that is free of cracks, ridges and compaction planes.

When shaping is done during finishing, all smoothed surfaces such as tire imprints and blade marks should be lightly scratched with a weeder, nail drag or spiketooth harrow to remove cleavage planes from the surface. A thin layer of soil-cement may not adhere to an underlying smooth area unless this has been dampened and roughened. The surface should be kept quite moist (optimum moisture or wetter) during finishing operations. Steel-wheel rollers are used to smooth out ridges left by initial pneumatic-tire rolling. Steel-wheel rollers have

Fig. 41. During final shaping, all smooth areas left by the blade and tires of the motor grader are removed with a scratcher.

Fig. 42. A hydraulically controlled weeder was used to remove smooth areas left by the motor grader on this job.

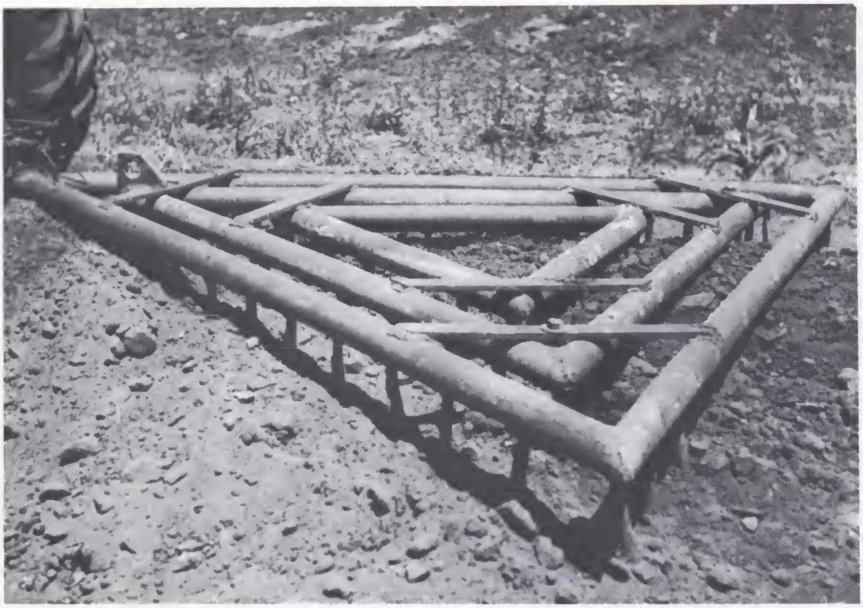

Fig. 43. This job-built nail drag is made of pipe welded into an "A" frame with pointed bolts for teeth.

Fig. 44. Tandem steel-wheel rollers are used during final rolling to set rock particles and to smooth out ridges.

Fig. 45. A broom drag is sometimes used to level out ridges and help produce a smooth surface finish.

Fig. 46. Light applications of water during finishing are usually necessary to replace moisture lost by evaporation.

Fig. 47. Smooth surfaces can be obtained on most soil-cement by "scalping" with a motor grader and rerolling with a pneumatic-tired roller.

particular advantage when rock is present in the surface. A broom drag is sometimes used advantageously to pull binder material in and around pieces of gravel that have been "set" by the steel-wheel roller. In lieu of using a steel roller, surfaces commonly are "scalped" with the motor grader and then rerolled with a pneumatic-tired roller to seal the surface. "Scalping" consists of lightly cutting or shaving off any small ridges left by the finishing equipment. Only a very thin depth (1/8 in.±) is cut and all material removed is bladed to the edge of the road and wasted. The final operation usually consists of a light application of water and rolling with a pneumatic-tired roller to seal the surface. The finished soil-cement is then cured. See page 18.

joint construction

At the end of each day's construction a transverse vertical construction joint is formed by cutting back into the completed soil-cement. This is done usually the last thing at night or the first thing the following morning. The material in front of the joint is prepared for processing in the next day's work. After mixing has been completed at the joint, it is cleaned of all dry and unmixed material and retrimmed if necessary. Mixed moist material is bladed into the area. The material next to the joint is then compacted thoroughly. During this stage of construction the joint is left slightly high; during final rolling it is trimmed to grade with the motor grader and rerolled. If bituminous material is used as a curing agent it is applied right up to the joint and sanded to prevent pickup.

Longitudinal joint construction is discussed in Chapter 4, page 56.

Fig. 48. A vertical transverse construction joint perpendicular to the centerline of the road is made at the end of each day's construction by cutting back a few feet into the completed work.

multiple-layer construction

Where the specified thickness of soil-cement base course exceeds the depth (usually 8 in.) that can be thoroughly mixed, moistened and compacted in one layer with available equipment, it must be constructed in multiple layers. No layer should be less than 4 in. thick. Final finishing of the lower layer does not have to be exact nor do surface compaction planes have to be removed, since they are too far from the final surface to be harmful. The completed lower layer can be cured with moist soil that is then used in building the top layer. The top layer may be constructed immediately or on the succeeding day, or it may be delayed for some time.

Fig. 49. The 12-in. soil-cement base course for this road was built in two 6-in. layers. The in-place soils were used in constructing the bottom layer and a borrow soil was used for the top layer.

chapter 3

STREET CONSTRUCTION

Construction of soil-cement streets is fundamentally the same as for roads. A 6-in. thickness of soil-cement is generally used. Where subgrade conditions are good and traffic is light, such as on some subdivision streets, a 5-in. and sometimes a 4-in. thickness is adequate. The type of bituminous surface used depends on several factors, as described in Chapter 1. For most residential streets a double bituminous surface treatment is satisfactory and low in first cost. Higher-type surfaces, road mix or plant mix, are more costly but sometimes justified.

The same basic control factors apply to soil-cement street construction as to road construction. Proper cement content, moisture content and density are essential. Laboratory testing of representative soil samples to establish an adequate cement content is a prerequisite to construction; simple field-control tests made during construction assure quality and eliminate guesswork (see Appendix B).

Fig. 50. Irving St., in Granville, N.Y., built in 1940, is typical of many soil-cement residential streets throughout the country.

details of street construction

Concrete curb and gutters are often included in a street paving project. They should be built before paving is started.

Soil materials should be balanced carefully and shaped to approximate crown and grade before soil-cement processing is started. Crown and grade should conform to any existing or planned structures such as curb and gutters, manholes, driveways and street intersections. This procedure simplifies and speeds up final finishing.

Most engineers and contractors prefer to remove manhole covers and frames before processing and to place a temporary heavy sheet-metal or plank cover over the manhole just below the depth to be processed. This permits processing over the manhole without any difficulty or delays. After final finishing and before soil-cement has hardened, the temporary cover is removed, the manhole frame and cover replaced and soil-cement hand-tamped tightly around the structure.

Sometimes it is expedient to process around manholes. When this is done, their locations should be marked clearly with flags or barricades to avoid damage by construction equipment. Other utility structures should be marked carefully ahead of processing so that equipment can be lifted over or guided around them.

Processing should be organized so that the full street width is completed each day of construction. To hasten construction, processing is done usually in successive construction lanes, which are usually some multiple of the mixing machine's width, until the full street width is mixed. This procedure avoids the construction of longitudinal joints.

Fig. 51. Soil-cement processing is hastened by removing manhole covers and frame and covering the hole with planks. The frame is reset to grade after processing is finished and before the bituminous surfacing is placed.

Fig. 52. A small plow easily moves the mix away from gutters for more thorough mixing.

Fig. 53. Steel plates attached to the motor-grader blade can be used to clean the gutter line.

Special attention to mixing adjacent to curbs and gutters and utility structures is necessary to insure that it is thorough. All soil and cement should be cleaned away from the gutter section for the full depth of processing to insure satisfactory mixing. The point of the motor-grader blade, a plow, or special cleaning devices are used for this purpose. Some final cleaning with square-pointed shovels may be needed.

Preliminary and final shaping of the section should be done with care to obtain proper grade adjacent to curb and gutter, manholes, driveways and street intersections. During shaping, a special guide is sometimes attached to the end of the motor-grader blade so that when it is resting on the gutter, the proper space for the subsequent bituminous surface will be obtained between the bottom of the gutter and the top of the soil-cement paving. If no curb and gutter exist, it is important to build the edge of the paving on line and at uniform grade to facilitate the placing of curb and gutter or utility structures at some later time.

The moist soil-cement must be compacted thoroughly adjacent to the curb and gutter and utility structures. The rear wheels of a motor grader frequently are used to obtain additional compaction along the gutter line.

Generally, construction is planned so that the turnaround area for equipment is at the end of the block within the street intersection. Construction joints are located at the end of the block being paved but should not be within the intersection unless paving is to end there. Sometimes the soil-cement paving is extended a few feet beyond this point and cut back when the cross-street is paved. The entire intersection is then paved as a part of the construction of the intersecting street. Miscellaneous areas to be paved, such as corners of intersections and approaches to alleys or unpaved streets, require separate mixing and finishing

Fig. 54. Mixed soil-cement is compacted next to the concrete gutter with the motor-grader wheels. The blade removes excess material.

but are usually handled without undue delay at the time the street is built.

The bituminous surface course may be placed as soon as the bituminous curing material has dried. Often all streets scheduled for construction are processed first. Then all surfacing can be placed in one continuous operation.

backfilling with soil-cement

It is often necessary to make cuts in street paving to excavate for utilities. Settlement of backfills may be prevented at these locations by using soil-cement or cement-modified soil. The excavated material is mixed with small quantities of cement, moistened to optimum and used for backfilling the excavation. Premixed soil-cement from a central mixing plant may also be used. Homemade hand tamps, pneumatic air tamps or various mechanical tamps may be used to compact the material tightly in thin layers. After the backfill is in place, the pavement may be rebuilt immediately without danger of settlement.

Soil-cement or cement-modified soil may be used also as a backfill material for walls and bridge abutments to keep settlement at a minimum.

chapter 4 AIRPORT PAVING

A 6-in. compacted depth of soil-cement with a suitable bituminous surfacing is generally used to pave small and medium-sized airports.* An analysis of subgrade conditions should be made to determine whether a greater pavement thickness is needed, particularly over clay subgrades and for heavier wheel loads. The Corps of Engineers, Civil Aeronautics Administration, U.S. Navy and others have published design manuals to serve as guides in design of airport pavements.

details of airport construction

The same principles of construction and the same fundamentals of control that apply to road construction (Chapter 2) apply as well to airport construction. A few details, however, require special comment. They are: (1) the necessity of having the material to proper crown and grade prior to processing; (2) a workable plan for processing; (3) construction of joints.

shaping material to crown and grade. Since there is little longitudinal and transverse displacement of soil during processing, accurate grading before construction starts will save time and make finishing easier. This is particularly

**Soil-Cement for Airports* is available free upon request only in the United States and Canada from Portland Cement Association.

Fig. 55. At Cairo, Ill., Municipal Airport, soil-cement was used to reconstruct the gravel-base runway, which had softened and rutted under traffic because of the very high water table.

Fig. 56. Soil-cement shoulders were constructed in 1942 along all the concrete runways at the Sioux City, Iowa, Municipal Airport.

true of large areas such as airport runways. A system of grade stakes is used for grade control.

plan of processing. The most practical plan of processing is one that reduces longitudinal and transverse construction joints to a minimum and permits finishing to be done longitudinally, thus providing a smooth surface. There are many processing plans but the one most generally used is to divide the area in processing sections of convenient length and width. Turnaround areas 40 to 50 ft. in width are left between successive sections and are later processed transversely. It is important that the end of each longitudinal section be built to grade. At the end of each day's construction the material next to the end and within the turnaround area is loosened to prevent its hardening.

joint construction. There are three types of joint that should be mentioned: (1) a longitudinal joint constructed adjacent to only partially hardened soil-cement, i.e., adjoining the preceding day's processing; (2) a longitudinal joint adjacent to hardened soil-cement, i.e., adjoining soil-cement processed three or four days previously; and (3) a transverse construction joint made when turnaround areas are processed—adjoining hardened soil-cement. The material next to all joints must be thoroughly pulverized, mixed with cement, moistened and tightly compacted. Compaction next to the joint can be accomplished with motor-grader wheels and by operating the compaction rollers as close to the joint as

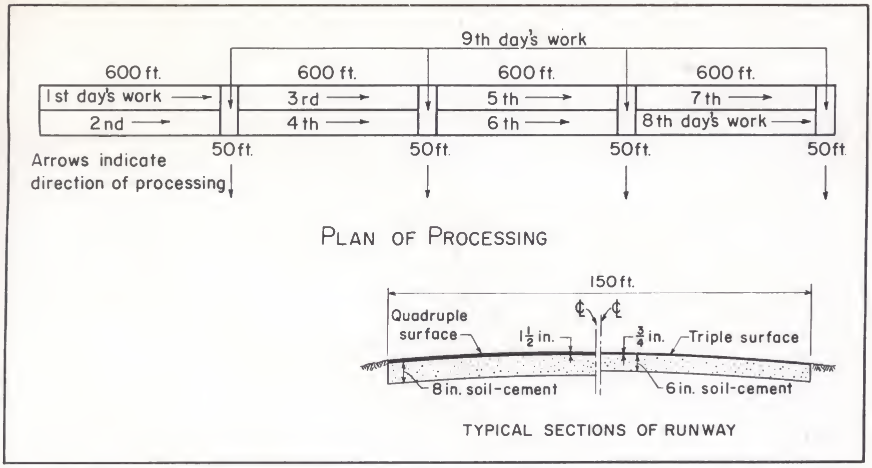

Fig. 57. This plan of processing was used in building runways at the Lubbock, Texas, Municipal Airport.

Fig. 58. Some joints can be made by cutting into the previously constructed work a few inches. String or stake lines should be set to define the joint location in order to avoid leaving a strip of unprocessed material.

possible. The location of all joints should be properly marked by stakes and string lines or by pegs so that streaks of unprocessed material will not occur along joints.

A longitudinal joint adjacent to partially hardened soil-cement can be constructed with most mixing equipment by merely cutting back into the previously constructed area a few inches. The amount of overlap is determined by digging back into the completed work until solid material is reached. Peg stakes or string lines are set as a guide for cement spreading and mixing.

If longitudinal and transverse joints are to be built after the soil-cement has hardened sufficiently that mixing equipment cannot cut it, the joint must be made by cutting to a string line with the point of the motor-grader blade. Some hand-trimming with axe and shovel may be needed. A disc mounted on the end of a blade makes a good edge-cutter. With a windrow-type mixing machine this method of joint construction is used for all joints.

Regardless of the method of construction the joint must be cut back to solid soil-cement and the material next to the joint must be properly pulverized, mixed with cement, moistened, compacted and finished level with the adjoining section; it must be free of scabs, etc. The 50-ft. turnaround areas are processed and finished transversely. Care should be taken to maintain proper grade.

chapter 5

STORAGE AND PARKING AREAS

A 6-in. compacted depth of soil-cement is usually built for storage and parking areas,* although a 5-in. thickness is satisfactory if subgrade conditions are favorable. A 4-in. thickness may be adequate in special cases.

The same soil-cement processing procedures and controls discussed in previous chapters apply to the construction of storage and parking areas. Accurate grading before processing starts and good grade control during processing will provide for rapid runoff of water and prevent puddles. Large storage and parking areas are processed by following the same general plan outlined for airport runways. For small projects, a processing plan that permits the fullest use of equipment in rather confined areas is used.

Most parking areas are surfaced with bituminous material, while storage areas for coal and similar materials are generally not surfaced. If the soil-cement is to be left unsurfaced the cement factor should be increased to provide additional abrasion resistance. This increase should be two percentage points for granular soils containing less than 50 per cent silt and clay and four percentage points for other soils.

**Soil-Cement—Low-Cost Pavement for Parking and Storage Areas* is available free on request only in the United States and Canada from Portland Cement Association.

Fig. 59. Parking areas are built in lanes. Note cement spreading at left, freshly mixed soil-cement in center and finishing with motor grader and roller at right.

chapter 6 WIDENING AND SHOULDERS

Equipment and procedures used for constructing soil-cement widening and shoulders* are basically the same as those for road construction (see Chapter 2) except that equipment widths must conform to the more limited space. Thorough mixing and compaction along the juncture of the old roadway edge are essential.

widening

Pavement widening is generally built thicker than ordinary pavement because it is subjected to greater stresses. Soil-cement widening in service today varies in thickness from 6 to 12 in., depending on traffic and subgrade conditions. Thicknesses greater than 8 in. are usually built in two layers. See Chapter 2, page 50, for details of multiple-layer construction.

construction. In cases where edges of the old roadway are found to be weak, the edge material may be ripped up and pulverized; then both edges and widening are processed in a single operation. Widening of 4 ft. or more can be processed in place.

For narrow widening the material may be bladed or trenched out and placed on the surface of the roadway for processing. The material is then mixed with a rotary mixer and motor grader, or a traveling mixing machine. The processed material is bladed back into the trench, compacted and finished.

When the in-place soil is not suitable, borrow soil may be used. The area to be widened is trenched and the excavated material is used for widening the shoulder. Borrow material, cement and water may be mixed in the trench or on the surface of the old roadway; or may be mixed in a central mixing plant, hauled to the

**Rebuild, Widen and Maintain Pavements with Soil-Cement* is available free on request only in the United States and Canada from Portland Cement Association.

Fig. 60. This soil-cement widening in Texas, 7 ft. wide and 6 in. thick, was built at the rate of two miles a day.

site and dumped through a spreader box into the trenched area. If a spreader box is not available, the mix may be dumped in a windrow near the edge of the pavement and bladed into the excavated area with a motor grader. After the mixture is in place, it is compacted and finished. Single-drum sheepsfoot rollers, trench rollers, job-made rollers and even the dual rear wheels of heavily loaded trucks have been used for compaction in narrow areas.

The completed widening is cured and surfaced with a suitable bituminous mixture. Frequently the entire old roadway and the widening are surfaced as one operation.

shoulders

In contrast to widening, which is designed and built to carry continuous traffic, shoulders are improved to provide better pavement performance and a safe emergency stopping or parking area. Improved shoulders increase the safety and traffic capacity of a road.

Soil-cement shoulders are stable under all weather conditions, provide rapid runoff of surface water and resist erosion and growth of vegetation.

Construction methods for shoulders are the same as those used for widening. Soil-cement shoulders are usually built 4 to 6 in. thick and may either be left unsurfaced or covered with a bituminous surfacing. If left uncovered, the shoulder will look much like the adjoining soil. For exposed soil-cement the cement factor should be increased to provide additional abrasion resistance. This increase should be two percentage points for granular soils containing less than 50 per cent silt and clay and four percentage points for other soils. Bituminous surfacings, when placed, usually are of a lower quality than the pavement surface and of different texture and color so that shoulders may be readily distinguished from the roadway; this encourages moving vehicles to remain in the traffic lanes.

Fig. 61. For narrow widening or shoulder projects, modification of equipment is sometimes necessary.

Fig. 62. An offset spray bar is sometimes used in building shoulders.

Fig. 63. A single-drum sheepsfoot roller was used for compaction on this job.

Fig. 64. Plant-mixed soil-cement was dumped into a special spreader box on this shoulder project.

Fig. 65. Soil-cement shoulders on U.S. Route 22 in Hunterdon County, N.J., were built in 1946.

chapter 7

SALVAGING FLEXIBLE PAVEMENTS

One of the most important uses of soil-cement is for salvaging or reconstructing granular base courses that have failed. Incorporation of portland cement with the base-course materials, often including the old bituminous surfacing, provides an economical means of salvaging and strengthening wornout granular-base pavements. Cement binds the granular particles together to form a paving material capable of withstanding moisture infiltration and frost action and of bridging over localized soft spots in the subgrade. Portland cement has been used with gravel, crushed stone, caliche, limerock, clay-gravel, sand-clay and similar granular-type materials to produce hardened soil-cement of more than average load-carrying capacity and serviceability. These materials require only a minimum of cement for adequate hardening.

incorporation of old surfacing

If the old bituminous mat is practically "dead," that is, has lost most of its flexibility and can be readily pulverized, it can be considered satisfactory for inclusion in the soil-cement mixture. If, on the other hand, the mat is "alive" and the bituminous material retains most of its original viscosity, it should not be incorporated in the mixture but should be removed. It may be considered worth while to reclaim and replace it on the soil-cement with the addition of new materials as needed.

Relatively thin surface treatments present no particular construction problem and can usually be readily scarified, broken up and pulverized. Thick, heavy mats may sometimes be difficult to handle and in some instances it may be uneconomical and impractical to break them up for use in the soil-cement mixture. The old mat must be pulverized sufficiently to meet the soil-cement gradation requirement

Fig. 66. Old bituminous mat is scarified and pulverized for incorporation in the soil-cement mix.

Fig. 67. A grid roller was used to break up the old surfacing on this job.

of 55 per cent passing a No. 4 sieve. Exceptionally well-graded materials may contain up to 65 per cent gravel and have sufficient fine material for adequate binding. The amount of old surfacing included in the soil mixture should generally not exceed 50 per cent of the total. The largest pieces of mat in the mixture after pulverization should not exceed 3 in.

Construction equipment used to scarify, break up and pulverize old surfacings includes rippers, motor-grader scarifiers, rotary mixers, preparizers, traveling mixing machines, disk harrows and various types of rollers. The hardness, thickness and type of surface will dictate the choice of equipment for a specific job.

Fig. 68. Old surfacing can be pulverized with a preparizer.

chapter 8

CEMENT-MODIFIED SOILS

When portland cement and water are added to and mixed with a soil, the chemical and physical properties of that soil are changed. Cement reduces the soil's plasticity, decreases its water-holding and volume-change capacities, and increases its bearing value and shearing strength. The degree of improvement depends on the quantity of cement used and the type of soil. Test procedures are given in *Soil-Cement Laboratory Handbook*.

In cement-modified soil, only enough cement is used to change the physical properties of the soil to the desired degree—less cement than is required to produce a truly hardened soil-cement. The soil becomes caked and semihardened.

Cement is used to modify both silt-clay and granular soils. These two applications are discussed separately.

granular soils

Substandard granular soils can be modified with portland cement to reduce or eliminate plasticity and to raise their bearing values to a point where they are acceptable for use as:

1. Base course for flexible pavements.
2. Subbase for pavements.

In certain areas, supplies of good granular materials for base courses are depleted, but there are abundant quantities of substandard materials with a high plasticity index (P.I.) and low bearing value. By the addition of relatively small quantities of portland cement, these substandard materials are made usable. The resultant product, however, is still primarily a granular-base material with all the characteristics of that type of construction. A much stronger and more durable base course can be obtained by adding the small additional amount of portland cement needed to harden these materials into rigid soil-cement.

Many miles of cement-modified granular-base-course roads have been built. Because of limited funds and quantities of substandard granular materials nearby or already in the road, this method of treatment has many applications.

Laboratory research and field experience show that the P.I. reduction and the

TABLE 4. permanency of P.I. reduction of cement-modified granular soil

	Cement content, per cent by volume		
	0	3	5
		P.I.	
Raw soil[a]	14	—	—
Laboratory mixture, age 7 days	—	4	NP[b]
Laboratory mixture after 30 cycles freeze-thaw	—	3	NP
Laboratory mixture after 60 cycles freeze-thaw	—	1	NP

[a] A-2-6(0) soil from Carroll County, Tenn.
[b] Nonplastic.

TABLE 5. permanency of bearing values of cement-modified granular soil

	CBR
Raw soil[a]	43
Laboratory mixture, 2 per cent cement by weight at age 7 days	255
Laboratory mixture, 2 per cent cement by weight after 60 cycles freeze-thaw	258
Laboratory mixture, 4 per cent cement by weight at age 7 days	485
Laboratory mixture, 4 per cent cement by weight after 60 cycles freeze-thaw	574

[a] A-1-b(0) disintegrated granite from Riverside County, Calif.

increase in bearing values of cement-modified granular soils are permanent. This, of course, is of primary importance.

silt-clay soils

Modification of silt-clay soils with cement applies to soils that have such high water-holding and volume-change capacities and such low bearing strengths that they are not suitable as subgrades. Cement-modified silt-clay soils have use:

1. As a modified subgrade for flexible or soil-cement pavements.
2. As a subbase for concrete paving where the only objective is to control moisture and volume changes in the subgrade.
3. To stabilize highway fills; to strengthen soft areas in the subgrade; as a trench and wall backfill material.

Present information strongly indicates that small quantities of cement or of chemicals do not modify and improve silt-clay soils sufficiently to make them satisfactory as a base-course material. The most effective means of treating these soils to make a satisfactory base-course material is to add sufficient cement to make hardened soil-cement.

Where these poor soils are encountered there generally are more favorable soils that can be used. Occasionally, however, it is cheaper and easier to modify and improve these poor soils by adding cement, particularly when the modified soils are to be used as a subbase for pavements and for stabilizing soft highway fills.

Cement-modified silt-clay soils should not be used as a subbase for concrete pavements to prevent pumping. Hardened soil-cement or cement-modified granular soils should be used for this purpose (see Chapter 9).

TABLE 6. permanency of cement-modified clay soil

	P.I.
Raw soil[a]	28½
Laboratory mixture containing 7 per cent cement	14½
Field mixture after construction, 7 per cent cement	10½
Field mixture after 6 years' service, 7 per cent cement	5-11

[a]A-7 clay from Comanche County, Okla.

construction

Construction procedures for producing cement-modified soil are about the same as those used in building soil-cement, although not as exacting. The same basic principles are followed: The soil is pulverized until 70 per cent passes the No. 4 sieve; the cement is uniformly incorporated; the optimum amount of moisture is added uniformly; and the mixture is compacted. This intimate contact of the soil and cement grains effects a slightly greater degree of modification than if the moistened mixture were left uncompacted. For this reason the mixture should be compacted the same day to obtain maximum benefit although this is not absolutely essential to the process of modifying soils. Also, by early compaction the mixture becomes caked and semihardened. Curing may be omitted.

chapter 9

SUBBASES FOR CONCRETE PAVING

In many states it has been common practice to construct subbases for concrete pavements over areas of poor subgrade to prevent damage from one or more of the following causes:

1. Pumping.
2. Swell and shrinkage in high-volume-change soils.
3. Frost action.

pumping

In areas where satisfactory granular subbase materials are expensive or nonexistent, hardened soil-cement or cement-modified granular soil subbases offer an economical and satisfactory alternative. Frequently cement treatment of in-place soils or nearby substandard granular materials results in a highly stable subbase of equal or lower cost than does importing subbase materials from an outside source.

Cement-treated subbases have high bearing values, which permits use of a more economical concrete pavement cross-section than would be required on the untreated subgrade. The saving in pavement cost partly compensates for the cost of treatment. In addition, the uniformity of support and the strength of the pavement foundation are greatly increased—a valuable asset to any pavement.

Treating material with cement nullifies any plasticity in the material and forms it into a stable mass that is highly resistant to consolidation and moisture-erosion at transverse joints. Further consolidation of subbases under the action of traffic is eliminated because the material is densified during construction and cemented in that state.

Fig. 69. In California, concrete pavement with soil-cement subgrade is often built for heavily traveled highways.

Millions of square yards of soil-cement subbases for concrete pavement have been built in California since 1945.* In most cases granular soils have been used to make a 4-in. thick hardened soil-cement subbase. Also, much of the concrete pavement on the Houston expressways was built on soil-cement subbases.** These hard subbases have little or no effect on the curling action of slabs or on cracking.

Other than in California and Texas, only a few test installations of soil-cement subbases for concrete pavements have been made. These were constructed with extremely heavy clayey soils. Valuable information is being obtained which will permit definite conclusions as to the effectiveness of clayey soil-cement subbases in preventing pumping of concrete pavements.

swell and shrinkage of high-volume-change subgrade soils

Unsatisfactory pavement performance caused by differential swell and shrinkage of high-volume-change soils is largely confined to semiarid areas where the native subgrade soils are heavy expansive clays. Rough-riding pavements with high joints and with loss or gain in crown are characteristic of this condition. Many investigations have led to the conclusion that the cure for this condition is to control the moisture content of the expansive subgrade soil before paving. Swell is at a minimum when these heavy clay subgrade soils are compacted to 90 and 95 per cent of standard density at a moisture content slightly in excess of optimum—near the plastic limit. In dry climates a blanketing course of granular material reduces moisture loss by evaporation and capillarity and also serves as a subbase to prevent pumping.

*Earl Withycombe, "Base Stabilization with Portland Cement." *Proceedings of the Fifth California Street and Highway Conference,* The University of California, February 4-6, 1953. Also refer to "Cement Treated Subgrade," in Section 17 of the California Division of Highways *Standard Specifications,* 1954.

**Frederick A. Harris, "Selection and Design of Semi-flexible and Conventional Type Pavements," a paper presented at the Thirty-Fifth Annual Meeting of the Highway Research Board, January 17-20, 1956.

Fig. 70. Four-inch soil-cement subbase is mixed between paving forms.

When this method is expensive, cement can be used to reduce the volume changes in the upper portion of expansive subgrades. Generally a 6-in. depth of treatment is adequate except for soils with excessive volume-change characteristics, in which case greater depths are desirable. Only enough cement is added to change the physical characteristics of the subgrade soil; this is cement-modified soil rather than hardened soil-cement. The cement content required to control volume change is determined by laboratory tests. Test procedures are given in *Soil-Cement Laboratory Handbook.* Details of extended laboratory and field tests and construction of one experimental project were reported in Highway Research Board *Proceedings of the Nineteenth Annual Meeting,* 1939, Vol. 19, pages 541-551.

damage from frost action

When soil-cement is used to prevent damage from differential frost-heave it should be constructed to the depth and width normally required for granular materials. Construction need not be for the full depth of frost penetration because the amount of heave is not equal to the depth of frozen material. Except for the most severe conditions, a combined thickness of pavement and soil-cement equal to half the depth of frost penetration should give satisfactory results.

sample is taken from bottom to top of the vertical face after the overburden has been removed. On small projects it is not uncommon to sample only the poorest soil on the job. The cement content required for this sample is used throughout the job.

Complete identification should be supplied with each sample.

tests

The complete details of soil-cement testing are given in *Soil-Cement Laboratory Handbook.* Only an outline is given here of the tests normally run on soil samples submitted for soil-cement construction. The objective of these tests is to determine the minimum cement content required to harden each soil adequately. The following tests are usually run:

- Soil identification tests
  - Grain size
  - Liquid limit
  - Plastic limit
- Soil-cement tests
  - Moisture-density relations—AASHO Designation: T134
  - Wetting and drying test—AASHO Designation: T135
  - Freezing and thawing test—AASHO Designation: T136

Unconfined compressive-strength tests are commonly made also.

The moisture-density test establishes the optimum moisture and maximum density at which test specimens should be molded. It also provides approximate values for use in construction. Wet-dry and freeze-thaw test specimens containing various amounts of cement are molded at optimum moisture and maximum density and tested after 7 days' hydration to determine the lowest cement content that will harden the soil adequately.

State highway department laboratories and many others are equipped to run the tests listed above. The tests have been modified and shortened considerably in the Portland Cement Association soil-cement laboratory. These modifications incorporate the information and experience gained since the original procedures were adopted as standard.

The amount of laboratory testing required for a given project depends on requirements of the constructing agency, number of soil types encountered, size of the job and similar factors. On major jobs, for instance, detailed tests are generally required and the minimum cement content that can be used safely is determined for each significant soil type on the job. The cost of laboratory tests for major projects is quite small in comparison with the total cost of the project. On smaller projects, particularly where testing facilities and manpower are limited, it is sometimes advantageous to conduct only enough laboratory tests to determine a safe, but not necessarily minimum, cement factor that can be used in construction. For emergency construction and for very small projects where laboratory testing facilities are not available or detailed testing is not possible or practical, a rapid and very simple test procedure can be used. This provides a safe cement factor but one that may be appreciably higher than the minimum for adequate hardness. These various test methods are given in detail in *Soil-Cement Laboratory Handbook.* In some areas special test methods and criteria have been developed specifically for local conditions. For the particular soils and climate involved, these locally developed test methods have also proved satisfactory.

Soil-Cement Laboratory, Form Sheet No. 13

Date tests completed ______

SUMMARY OF TESTS ON SOIL-CEMENT MIXTURES
PORTLAND CEMENT ASSOCIATION
SOIL-CEMENT BUREAU

PCA Soil No. ______

State ______ Project ______

Field Project No. ______

County ______

Sampling location Represents top 6 in. of old gravel road, taken at sta. 50+00

GRADATION

Per cent passing	Soil mortar	Total sample
3-in. sieve		100
3/4-in. sieve		95
No. 4 sieve (4.76mm.)		82
No. 10 sieve (2.00mm.)	100	66
No. 18 sieve (1.00mm.)	83	55
No. 35 sieve (0.50mm.)	68	45
No. 40 sieve (0.42mm.)	65	43
No. 60 sieve (0.25mm.)	55	36
No. 140 sieve (0.105mm.)	38	25
No. 200 sieve (0.074mm.)	32	21
Per cent smaller than		
0.05 mm.	26	17
0.005mm.	12	8
0.002mm.	9	6

U.S. DEP'T. OF AGRICULTURE SOIL CLASSIFICATION

Soil series ______
Soil horizon ______
Textural class Gr. Coarse Sandy Loom
Color of moist soil Brown

PHYSICAL TEST CONSTANTS
L. L. 26
P. I. 8

AASHO SOIL CLASSIFICATION
A-2-4(0)

COMPRESSIVE STRENGTH, psi *			
Cement content, % by wt.	Age when tested, days		
	two	seven	twenty-eight
6	295	540	770
10	340	795	965

*Specimens saturated in water before testing

DATA FROM WET-DRY AND FREEZE-THAW SPECIMENS		
Cement content, % by wt.	Total soil-cement loss, %	
	Wet-Dry	Freeze-Thaw
5.8		21
7.0	8	9
9.0		2

PLUS NO. 4 MATERIAL
Absorption, % 2.0
Bulk sp. gravity 2.55

RECOMMENDATIONS

Recommended cement content 8.5 % by volume
which is 5.99 lb. per sq. yd. per inch of compacted thickness.

Laboratory optimum moisture content** 11.5 %

Laboratory maximum density** 121.2 lb. per cu. ft.

**Moisture-density test made on total sample using 3/4-in. maximum size material. Tests made in field toward end of damp mix govern field control.

Remarks: ______

Fig. 72. Summary of laboratory test data.

test results and their use in the field

A summary of typical laboratory test data is shown in Fig. 72. Similar data are usually reported for each soil sample submitted. Recommendations of cement content are given as per cent cement by volume of compacted soil-cement mixture. Fig. 74, page 77, may be used to convert recommended cement content by volume to the corresponding cement content by weight of oven-dry soil.

Computations for spreading the correct quantities of cement during construction are given on page 76 of Appendix B. The summary of laboratory data, Fig. 72, also shows the laboratory maximum density and optimum moisture content. These data can be used to start a project but moisture-density tests performed in the field during construction govern field control.

appendix B INSPECTION AND FIELD CONTROL

The purpose of inspection and field control is to assure that the results set out in the plans and specifications are obtained.

In soil-cement construction there are three major control factors. They are:

1. Adequate cement content.
2. Proper moisture content.
3. Proper compaction.

A thorough mix of pulverized soil, cement and water must also be obtained. To assist in attaining these objectives, the following list of check items is given:

1. Inspection of the grade and correction of all soft subgrade areas.
2. Proper identification of the soils so that the correct percentage of cement may be added to each soil.
3. Adequate pulverization.
4. Calculation of cement spread.
5. Checking cement spread.
6. Incorporation of the correct amount of moisture.
7. Uniformity of mix; depth and width of treatment.
8. Degree of compaction—density.
9. Proper finishing.
10. Adequate curing.

Proper inspection is primarily good judgment based on experience and the requirements of the plans and specifications. Many of the items are automatically controlled as the builder learns proper construction procedures. Tests and calculations are basically the same as those used for controlling the compaction of earth work.

inspection of roadway

Before construction starts, the area to be paved should be graded and shaped as required to construct the base course to the lines, grades, thickness and typical cross-section that are shown on the plans.

During grading, all debris should be removed and all soft subgrade areas corrected. The latter is important since adequate compaction cannot be obtained in the base course if the subgrade does not support the compacting and finishing equipment. Most soft areas can be easily detected by observing the stability as the motor grader shapes the area prior to soil-cement processing.

identification of soils

The success of soil-cement depends mainly on mixing the correct amount of cement with the soil. The soil survey report, laboratory test reports, plans, specifications and the engineer's knowledge of the soils on the job supply the information needed. On most jobs this is a simple step since only one or possibly two cement contents are needed. Usually cement requirements and soil types have been established long before construction starts, but they should be checked.

pulverization

Most soils used in soil-cement construction need little or no preliminary pulverization. Specifications generally require that at the time of compaction 80 per

Fig. 73. Field tests determine the degree of pulverization obtained.

cent of the soil-cement mixture pass the No. 4 sieve and 100 per cent pass the 1-in. sieve, exclusive of any gravel or stone retained on these sieves. If a clayey soil is being used, the degree of pulverization needs to be checked. The degree of pulverization required before cement is added depends on the soil and the mixing equipment.

A pulverization test is made by screening a representative sample over a No. 4 sieve and computing the percentage that passes.

$$\text{Per cent pulverization} = \frac{\begin{array}{c}\text{Dry weight of}\\ \text{soil-cement mixture passing No. 4 sieve}\end{array}}{\begin{array}{c}\text{Dry weight of total sample exclusive}\\ \text{of gravel retained on No. 4 sieve}\end{array}} \times 100.$$

For practical purposes this test is usually run with wet weights instead of correcting each portion for moisture. This is reasonably accurate if the moisture content of each portion is about the same. Usually no correction is made for the weight of cement present.

calculation of cement spread

Bulk or bag cement may be used. The plans and special provisions specify the quantity of cement to be spread, determined from laboratory tests as outlined in Appendix A. Generally the cement content is specified as per cent cement by volume of compacted mixture. Specified cement contents by weight of oven-dry soil can be converted to cement contents by volume if the maximum density is known (see Fig. 74). One bag of cement weighs 94 lb. and its volume is considered to be 1 cu.ft.

Before cement is spread, the area to be processed should be shaped to approximate grade if the soils are processed in place. If the soils are processed in windrows the quantity of soil in each windrow must be known—either the oven-dry weight of soil per lineal foot of windrow or the volume of roadway per lineal foot represented by each windrow.

Figs. 75 and 76 and Table 7 can be used to convert specified cement contents to the quantity of cement per square yard or to the quantity of cement per lineal foot.

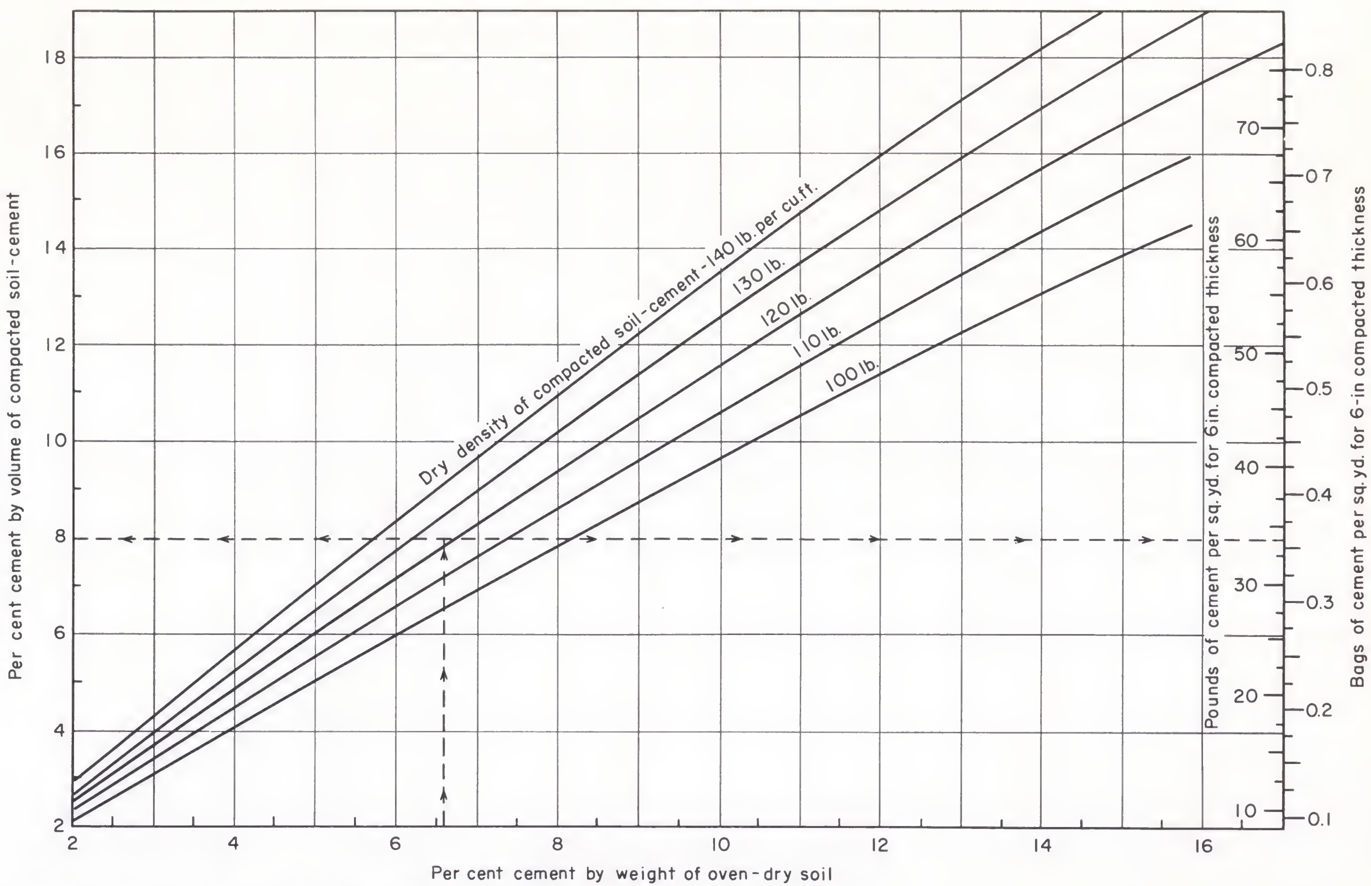

Fig. 74. Cement factor conversion chart. Per cent cement by volume of compacted soil-cement vs. per cent cement by weight of oven-dry soil vs. quantity of cement per sq.yd. for a 6-in. compacted thickness for known dry densities of soil-cement.

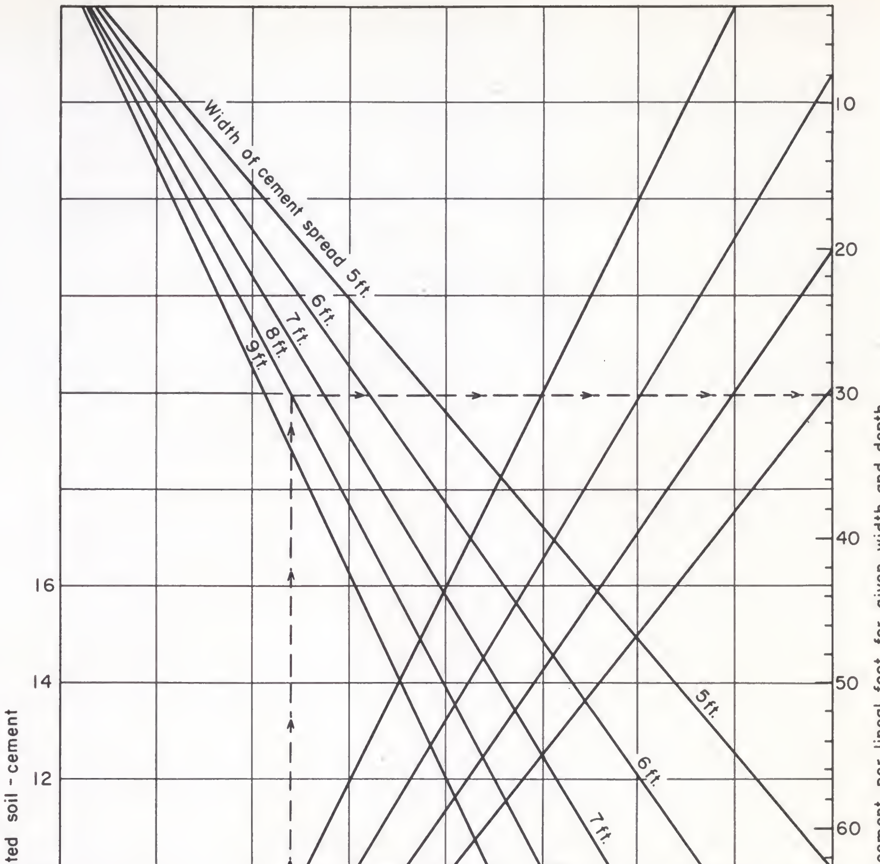

Fig. 75. Pounds of cement required per lineal foot for various widths and depths for specified cement contents by volume.

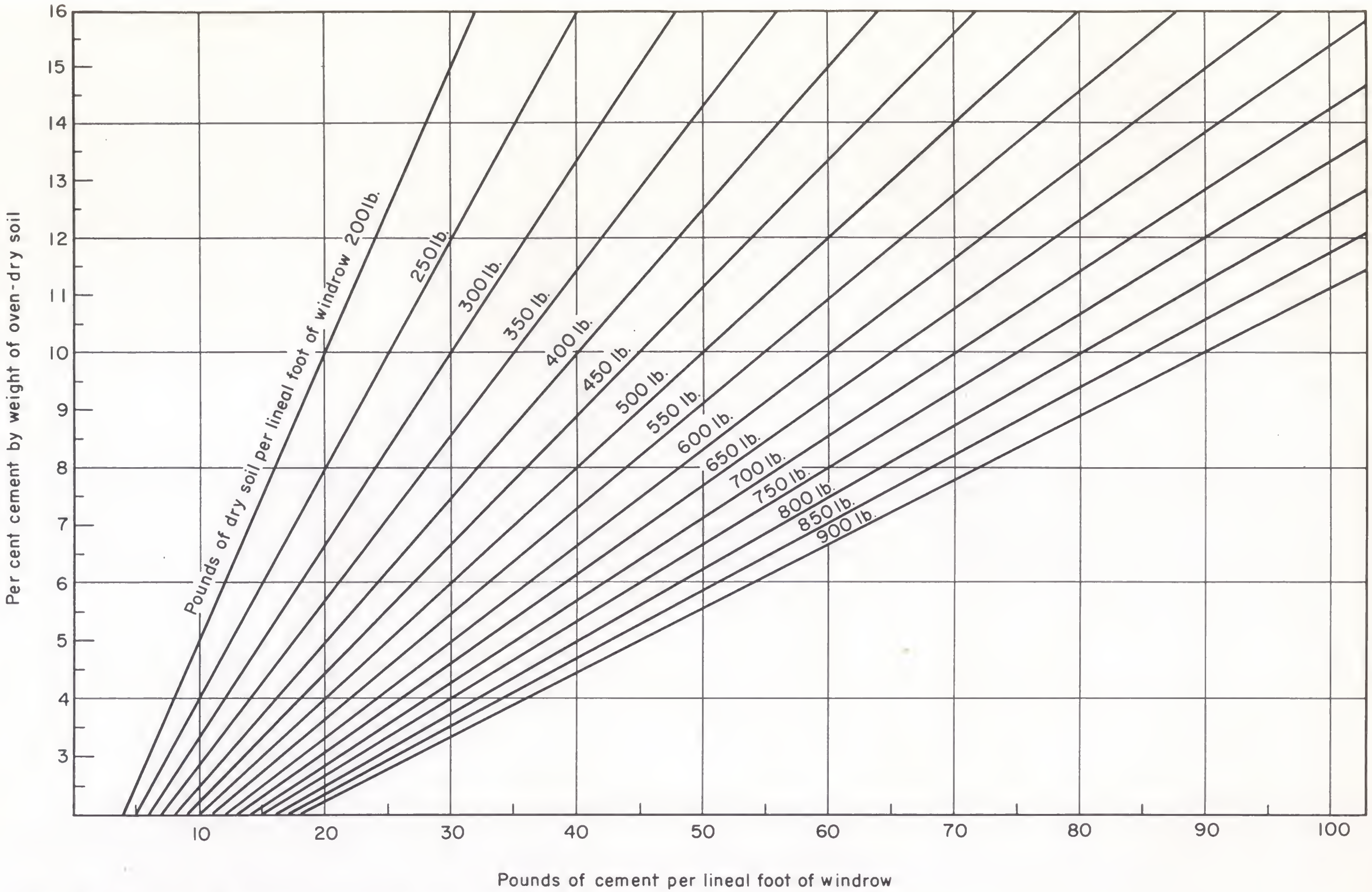

Fig. 76. Pounds of cement required per lineal foot of windrow for specified cement contents by weight.

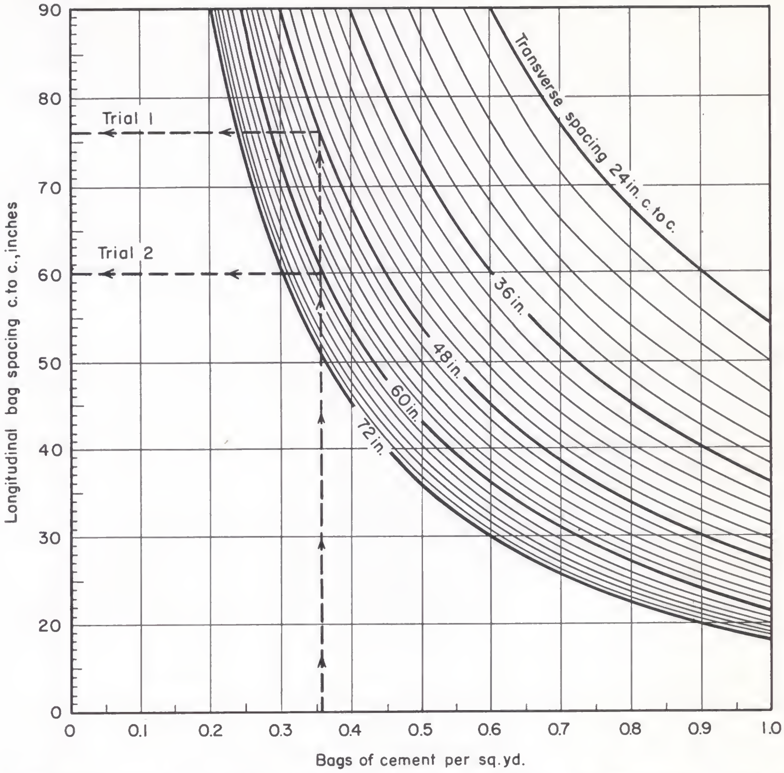

Fig. 77. Transverse and longitudinal spacing of bags of portland cement for specified cement contents.

TABLE 7. cement spread requirements per square yard

Per cent cement by volume	Compacted depth, in. 5		6		7		8	
	Lb.	Bag	Lb.	Bag	Lb.	Bag	Lb.	Bag
4	14.1	0.15	16.9	0.18	19.75	0.211	22.55	0.24
5	17.6	0.188	21.2	0.225	24.8	0.263	28.2	0.30
6	21.4	0.225	25.4	0.27	29.7	0.315	33.9	0.36
7	24.7	0.263	29.6	0.315	34.6	0.368	39.5	0.42
8	28.2	0.30	33.8	0.36	39.5	0.421	45.1	0.48
9	31.8	0.338	38.1	0.405	44.6	0.474	50.8	0.54
10	35.2	0.375	42.3	0.45	49.5	0.527	56.4	0.60
11	38.8	0.413	46.5	0.495	54.4	0.579	62.0	0.66
12	42.3	0.45	50.8	0.54	59.4	0.632	67.7	0.72
13	46.8	0.488	55.0	0.585	64.4	0.684	73.3	0.78
14	49.4	0.525	59.2	0.63	69.3	0.737	78.9	0.84
15	53.0	0.563	63.5	0.675	74.3	0.79	84.6	0.90
16	56.4	0.60	67.7	0.72	79.2	0.842	90.2	0.96

example 1. bulk-cement spread

GIVEN: Cement content by volume required .... 8 per cent.
Depth of compacted soil-cement.............................. 6 in.
Width of spread... 8 ft.
Weight of truckload of cement................................. 7,520 lb.

REQUIRED: Lineal distance that one truckload of cement should travel to spread the required amount of cement—8 per cent in this example.

PROCEDURE:
1. Enter Fig. 75 on left side at the required cement content by volume—8 per cent in this example.
2. Proceed horizontally to depth line—6 in. in this example.
3. Then proceed vertically to intersection with line representing the width of spread—8 ft. in this example.
4. From this intersection proceed horizontally to the right side of the chart and read pounds of cement per lineal foot—30.0 lb.

ANSWER: Divide the total weight of cement on truck by the pounds per lineal foot required.

$\frac{7{,}520}{30.0} = 250.7$ ft. The answer is the required distance of travel for this truckload to obtain the specified cement spread.

Bags of cement should be spaced at practically equal transverse and longitudinal intervals. Bag spacings can be obtained from Fig. 77.

example 2. bag-cement spread

GIVEN: Width of roadway.. 20 ft.
Cement content by volume required......................... 8 per cent.
Depth of processing... 6 in.

REQUIRED: Transverse and longitudinal spacing of bags.

PROCEDURE: Trial 1.
1. From Table 7 obtain correct amount of cement required per square yard for 6-in. depth and 8 per cent cement by volume: 0.36 bag per sq.yd.
2. Assume five longitudinal rows of cement bags across roadway. Divide width of roadway by number of rows to determine transverse spacing:

$$\frac{20}{5} = 4 \text{ ft.} = 48 \text{ in.}$$

3. Enter Fig. 77 at 0.36 bag per sq.yd. and proceed vertically to intersection with 48-in. curve; then proceed horizontally to edge of chart and read longitudinal spacing of 76 in.

Note: Longitudinal and transverse spacing should be approximately equal. This was not attained in Trial 1; therefore, proceed with Trial 2.

Trial 2.
1. Assume four longitudinal rows of cement bags across roadway. Transverse spacing equals:

$$\frac{20}{4} = 5 \text{ ft.} = 60 \text{ in.}$$

2. Enter Fig. 77 at 0.36 bag per sq.yd. and proceed vertically to intersection with 60-in. curve; then proceed horizontally to edge of chart and read longitudinal spacing of 60 in.

ANSWER: Bags should be placed in four longitudinal rows 60 in. apart with 60-in. longitudinal spacing between bags.

check on cement spread

A check on the accuracy of the cement spread is advisable to insure that the proper quantity is actually being applied. When bulk cement is being used, this is done in two ways:

1. Place a canvas, usually 1 sq.yd. in area, on the roadway ahead of the cement spreader. After the spreader has passed, pick up the canvas carefully and weigh the cement collected on it.

2. Check the distance or area over which a known weight of a truckload of cement is spread. For instance, in Example 1, a 7,520-lb. load of cement was supposed to cover an area 250.7 ft. by 8 ft. or 222.9 sq.yd. If the truck traveled 245.0 ft., the quantity of cement actually spread would be:

$$7{,}520 \text{ lb.} \div \frac{(245.0 \text{ ft.} \times 8 \text{ ft.})}{9 \text{ sq.ft.}} = 34.5 \text{ lb. per sq.yd.}$$

This is compared to 30.0 lb. per sq.yd., as required in Example 1. Therefore, the spreader should be adjusted to spread less cement per square yard.

Bulk cement that is spread mechanically in the top of a windrow of soil may be checked by pushing two metal plates into the top of the windrow exactly 1 ft. apart. All cement between the plates is carefully scraped out and weighed. This method gives directly the quantity of cement spread per lineal foot.

Generally, checking the cement on the square yard basis is used to adjust the spreader, while a final check is made by figuring the quantity of cement spread per unit area from the area covered by a truckload of cement. Bag cement is checked by counting the number of bags actually placed per 100-ft. station. It is desirable to keep a continuous check on cement-spreading operations.

incorporation of correct amount of moisture

Proper moisture content is one of the three basic control factors of soil-cement construction. The approximate optimum moisture content, as determined from the laboratory tests, is used in starting processing operations. A moisture-density test made in the field on a representative sample taken at the conclusion of moist-mixing determines the optimum moisture and maximum density for field control. This procedure takes into consideration two factors:

1. Any changes in the optimum moisture and maximum density resulting from minor changes in soil.
2. Any changes in the optimum moisture and maximum density resulting from lengthy mixing.

The optimum moisture and maximum density, as determined in the laboratory, may be used to govern field control if the mixing cycle is short (less than 30 minutes), if compaction starts immediately and if the soil is identical to that used in the tests.

moisture-density test. The moisture-density test determines two of the basic control factors: the optimum moisture at which the mixture should be

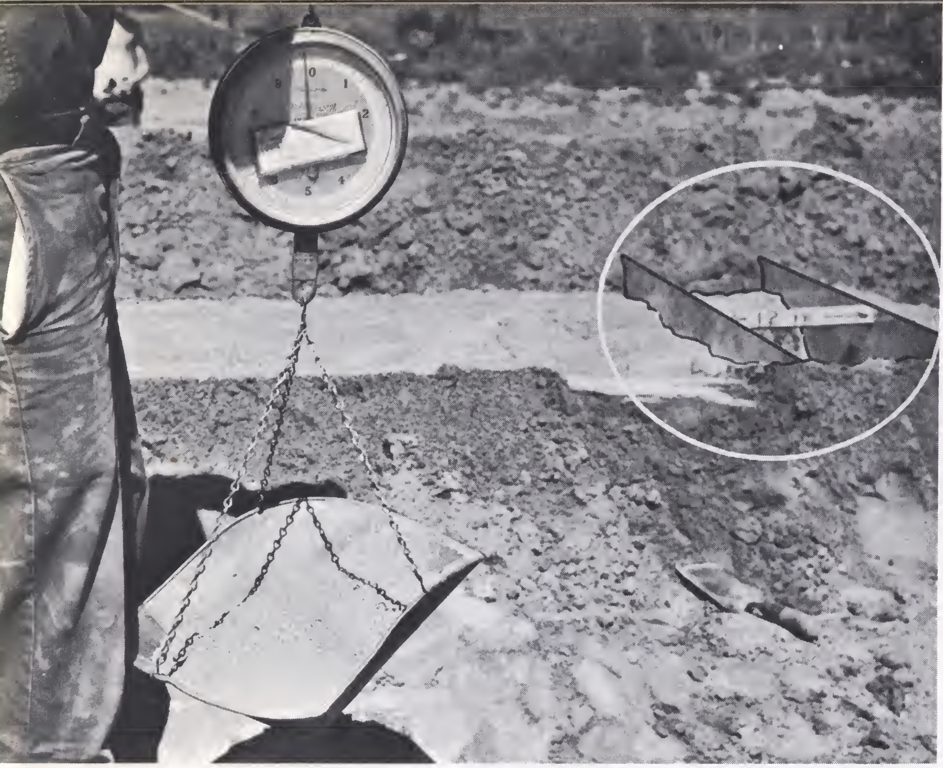

Fig. 78. The quantity of bulk cement spread on the top of a windrow is checked by collecting and weighing the cement spread on 1 lin.ft. of windrow.

compacted in the field and the minimum density to which it should be compacted. This test is run in accordance with the standard method AASHO Designation: T134 with certain modifications. When gravel is present in the sample the test is run on the total sample, i.e., soil and gravel. The maximum size of gravel is limited to ¾ in. Gravel larger than ¾ in. is replaced with an equivalent weight of No. 4 to ¾-in. size gravel. The percentage of gravel larger than the No. 4 sieve should be recorded. This procedure results in an optimum moisture and maximum density more applicable to field conditions. When the soil contains no gravel, the standard test is applicable.

In a moisture-density test, the soil-cement mixture is packed in three layers of equal thickness into a 1/30-cu.ft. mold with collar attachment, sometimes called a Proctor mold. Each layer is compacted by 25 uniformly spaced vertical blows of a 5½-lb. rammer with a 2-in. diameter striking face and a free fall of 12 in. The thickness of the layers is controlled so that the third layer extends above the top of the mold about ⅓ in. into the collar extension. After the collar is removed, the soil-cement is trimmed to the exact size of the mold; then the assembly is weighed. The damp weight of the compacted material at different moisture contents is determined in this manner. The moisture content of each trial is determined and the dry weights are calculated and plotted against moisture content to form a moisture-density curve. The optimum moisture content is that at which the greatest dry density is obtained in the test. This density is referred to as the "maximum density," and is approximately the minimum density to use in soil-cement construction.

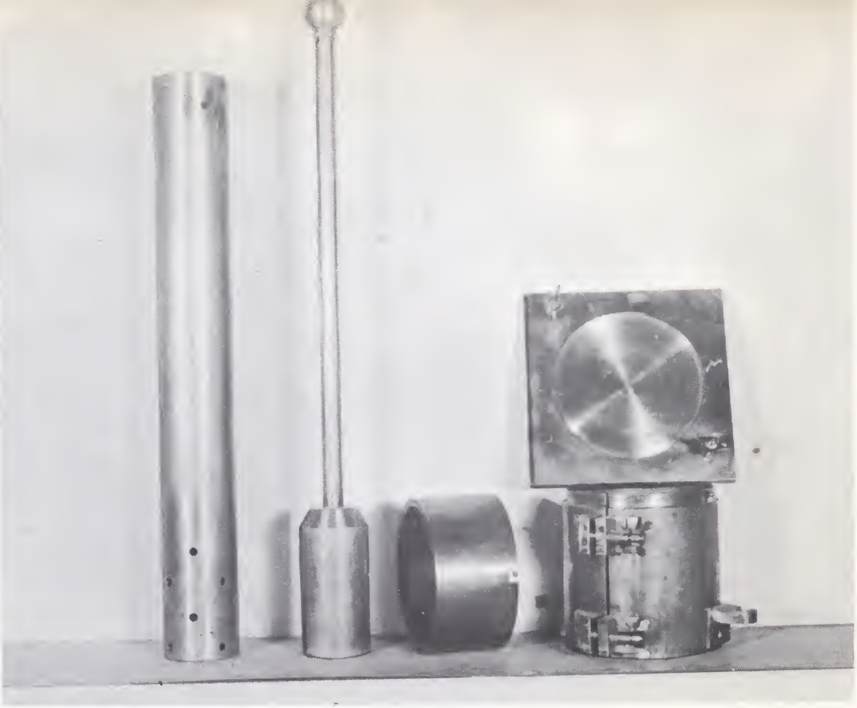

Fig. 79. Moisture-density mold and rammer. This split-type mold facilitates removal of test specimens during field testing.

Many engineers have devised short cuts in making field moisture-density tests. For instance, if the field sample obtained is near optimum moisture, the sample is split in half and one portion is used to establish the point near the peak of the moisture-density curve. This same material is then re-used with the addition of a small increment of water to establish a point on the wet side of the curve. The other half of the original field sample, which has dried slightly in the interim, is then used to establish the dry point on the curve. (See Fig. 81.) After a little experience, an operator can accurately judge when a soil or soil-cement mixture is at optimum moisture by its feel and by the way it packs into the mold. Such short cuts decrease the time required to make a moisture-density test and produce reliable results when performed by an experienced operator.

These field moisture-density tests are important and should be conducted regularly to control construction variables and assure satisfactory results.

moisture test. In order to estimate water-spreading requirements, representative moisture samples are obtained from the raw soil prior to mixing, or from the dry soil-cement mix before water is applied.

The samples are weighed, and then dried and reweighed. The moisture content is computed as follows:

$$\text{Per cent moisture} = \frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100.$$

For field testing, samples containing gravel should weigh 750 grams. Samples containing no gravel should weigh 400 grams. Tables 8 and 9 have been prepared to show moisture contents when an original moist sample of fixed weight is weighed out and its final dry weight determined.

moisture-density data

Trial	Wet density, lb. per cu.ft.	Moisture content, per cent	Dry density, lb. per cu.ft.
1	124.1	8.3	114.6
2	128.8	10.5	116.6
3	130.8	12.6	116.2
4	130.5	14.4	114.1

Maximum dry density: 117.2 lb. per cu.ft.
Optimum moisture: 11.3 per cent.

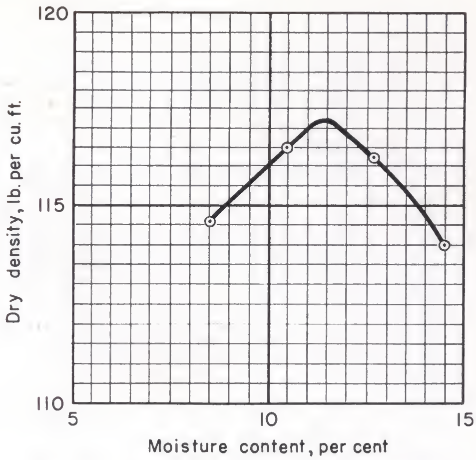

Fig. 80. Typical moisture-density data and curve.

moisture-density data

Trial	Wet density, lb. per cu.ft.	Moisture content, per cent	Dry density, lb. per cu.ft.
1	130.4	10.0	118.5
2	130.4	11.5	117.0
3	128.1	9.0	117.5

Maximum dry density: 118.5 lb. per cu.ft.
Optimum moisture: 10.3 per cent.

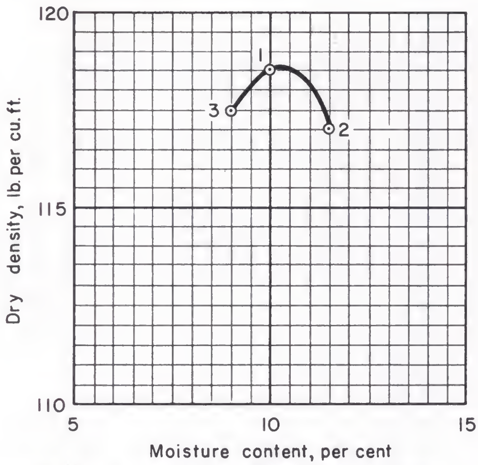

Fig. 81. A moisture-density curve on material at or near optimum moisture can be established by running the test in the order indicated above.

water requirements. The approximate percentage of water required is equal to the difference between the optimum moisture content and the moisture content of the dry soil-cement mix, as determined above. Approximately 2 per cent additional moisture must be added to compensate for the dry cement added to the soil if the moisture test was made on the raw soil prior to the addition of cement. Required moisture contents in per cent can be converted into gallons by using Fig. 82.

TABLE 8. moisture contents of samples weighing 750 grams wet and having final dry weight shown

Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture
749.0	0.1	729.0	2.9	709.0	5.8	689.0	8.9	669.0	12.1	649.0	15.6	629.0	19.2	609.0	23.2
748.0	0.3	728.0	3.0	708.0	5.9	688.0	9.0	668.0	12.3	648.0	15.7	628.0	19.4	608.0	23.4
747.0	0.4	727.0	3.2	707.0	6.1	687.0	9.2	667.0	12.4	647.0	15.9	627.0	19.6	607.0	23.6
746.0	0.5	726.0	3.3	706.0	6.2	686.0	9.3	666.0	12.6	646.0	16.1	626.0	19.8	606.0	23.8
745.0	0.7	725.0	3.4	705.0	6.4	685.0	9.5	665.0	12.8	645.0	16.3	625.0	20.0	605.0	24.0
744.0	0.8	724.0	3.6	704.0	6.5	684.0	9.6	664.0	13.0	644.0	16.5	624.0	20.2	604.0	24.2
743.0	0.9	723.0	3.7	703.0	6.7	683.0	9.8	663.0	13.1	643.0	16.6	623.0	20.4	603.0	24.4
742.0	1.1	722.0	3.9	702.0	6.8	682.0	10.0	662.0	13.3	642.0	16.8	622.0	20.6	602.0	24.6
741.0	1.2	721.0	4.0	701.0	7.0	681.0	10.1	661.0	13.5	641.0	17.0	621.0	20.8	601.0	24.8
740.0	1.4	720.0	4.2	700.0	7.1	680.0	10.3	660.0	13.6	640.0	17.2	620.0	21.0	600.0	25.0
739.0	1.5	719.0	4.3	699.0	7.3	679.0	10.5	659.0	13.8	639.0	17.4	619.0	21.2	599.0	25.2
738.0	1.6	718.0	4.5	698.0	7.5	678.0	10.6	658.0	14.0	638.0	17.6	618.0	21.4	598.0	25.4
737.0	1.8	717.0	4.6	697.0	7.6	677.0	10.8	657.0	14.2	637.0	17.7	617.0	21.6	597.0	25.6
736.0	1.9	716.0	4.7	696.0	7.8	676.0	10.9	656.0	14.3	636.0	17.9	616.0	21.8	596.0	25.8
735.0	2.0	715.0	4.9	695.0	7.9	675.0	11.1	655.0	14.5	635.0	18.1	615.0	22.0	595.0	26.0
734.0	2.2	714.0	5.0	694.0	8.1	674.0	11.3	654.0	14.7	634.0	18.3	614.0	22.1	594.0	26.3
733.0	2.3	713.0	5.2	693.0	8.2	673.0	11.4	653.0	14.9	633.0	18.5	613.0	22.3	593.0	26.5
732.0	2.5	712.0	5.3	692.0	8.4	672.0	11.6	652.0	15.0	632.0	18.7	612.0	22.5	592.0	26.7
731.0	2.6	711.0	5.5	691.0	8.5	671.0	11.8	651.0	15.2	631.0	18.9	611.0	22.7	591.0	26.9
730.0	2.7	710.0	5.6	690.0	8.7	670.0	11.9	650.0	15.4	630.0	19.0	610.0	23.0	590.0	27.1

TABLE 9. moisture contents of samples weighing 400 grams wet and having final dry weight shown

Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture	Dry weight, grams	Per cent moisture
399.5	0.1	389.5	2.7	379.5	5.4	369.5	8.3	359.5	11.3	349.5	14.4	339.5	17.8	329.5	21.4
399.0	0.3	389.0	2.8	379.0	5.5	369.0	8.4	359.0	11.4	349.0	14.6	339.0	18.0	329.0	21.6
398.5	0.4	388.5	3.0	378.5	5.7	368.5	8.5	358.5	11.6	348.5	14.8	338.5	18.2	328.5	21.8
398.0	0.5	388.0	3.1	378.0	5.8	368.0	8.7	358.0	11.7	348.0	14.9	338.0	18.3	328.0	22.0
397.5	0.6	387.5	3.2	377.5	6.0	367.5	8.8	357.5	11.9	347.5	15.1	337.5	18.5	327.5	22.1
397.0	0.8	387.0	3.4	377.0	6.1	367.0	9.0	357.0	12.0	347.0	15.3	337.0	18.7	327.0	22.3
396.5	0.9	386.5	3.5	376.5	6.2	366.5	9.1	356.5	12.2	346.5	15.4	336.5	18.9	326.5	22.5
396.0	1.0	386.0	3.6	376.0	6.4	366.0	9.3	356.0	12.4	346.0	15.6	336.0	19.0	326.0	22.7
395.5	1.1	385.5	3.8	375.5	6.5	365.5	9.4	355.5	12.5	345.5	15.8	335.5	19.2	325.5	22.9
395.0	1.3	385.0	3.9	375.0	6.7	365.0	9.6	355.0	12.7	345.0	15.9	335.0	19.4	325.0	23.1
394.5	1.4	384.5	4.0	374.5	6.8	364.5	9.7	354.5	12.8	344.5	16.1	334.5	19.6	324.5	23.3
394.0	1.5	384.0	4.2	374.0	7.0	364.0	9.9	354.0	13.0	344.0	16.3	334.0	19.8	324.0	23.5
393.5	1.7	383.5	4.3	373.5	7.1	363.5	10.0	353.5	13.2	343.5	16.4	333.5	19.9	323.5	23.6
393.0	1.8	383.0	4.4	373.0	7.2	363.0	10.2	353.0	13.3	343.0	16.6	333.0	20.1	323.0	23.8
392.5	1.9	382.5	4.6	372.5	7.4	362.5	10.3	352.5	13.5	342.5	16.8	332.5	20.3	322.5	24.0
392.0	2.0	382.0	4.7	372.0	7.5	362.0	10.5	352.0	13.6	342.0	17.0	332.0	20.5	322.0	24.2
391.5	2.2	381.5	4.8	371.5	7.7	361.5	10.7	351.5	13.8	341.5	17.1	331.5	20.7	321.5	24.4
391.0	2.3	381.0	5.0	371.0	7.8	361.0	10.8	351.0	14.0	341.0	17.3	331.0	20.8	321.0	24.6
390.5	2.4	380.5	5.1	370.5	8.0	360.5	11.0	350.5	14.1	340.5	17.5	330.5	21.0	320.5	24.8
390.0	2.6	380.0	5.3	370.0	8.1	360.0	11.1	350.0	14.3	340.0	17.6	330.0	21.2	320.0	25.0

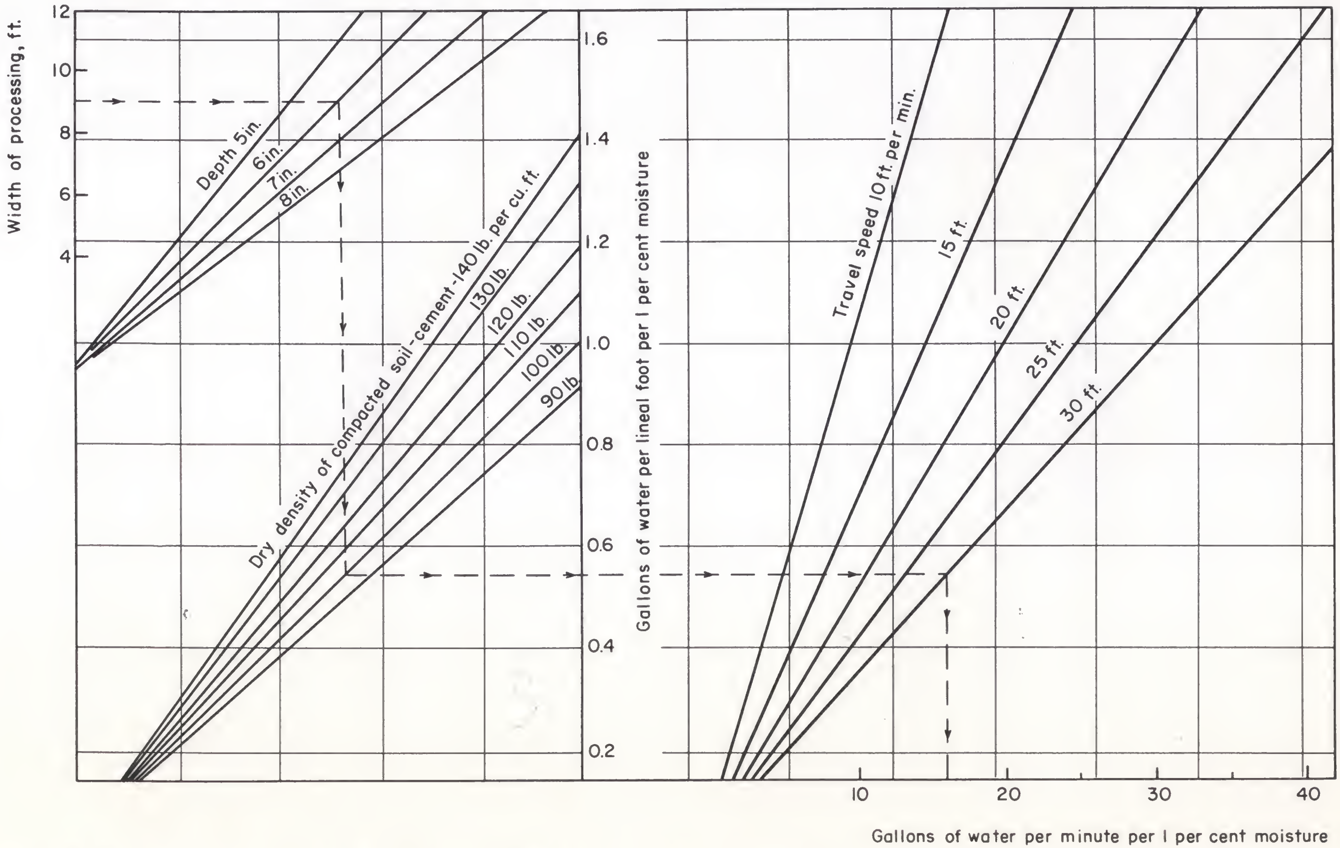

Fig. 82. Water required to raise the moisture content one percentage point.

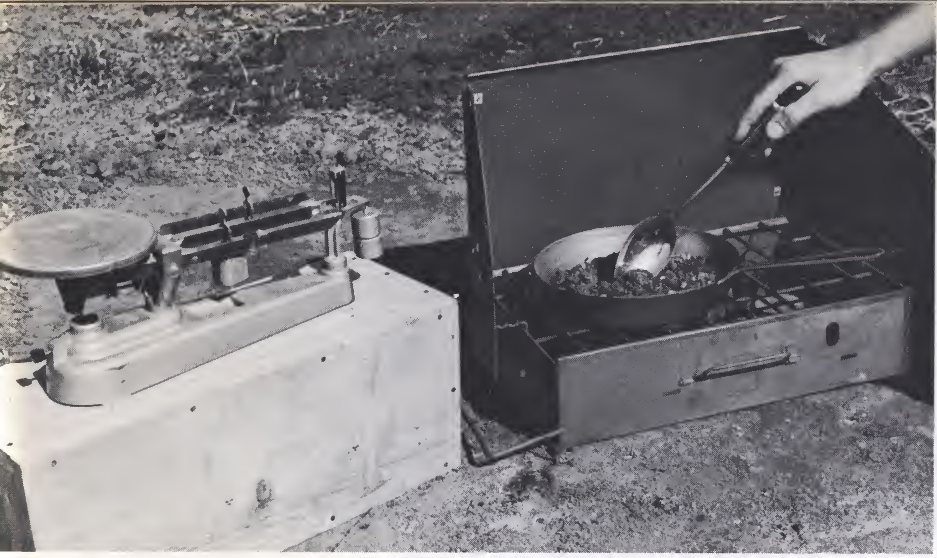

Fig. 83. A frying pan and a gasoline stove are commonly used to dry samples in the field laboratory.

example:

GIVEN: Field moisture content of raw soil . . . . 6 per cent.
Laboratory optimum moisture content . . . . 14 per cent.
Maximum density . . . . 100 lb. per cu.ft.
Processing depth . . . . 6 in.
Mixing width . . . . 9 ft.
Mixing rate . . . . 30 ft. per minute.

REQUIRED: Gallons of water per lineal foot.
Gallons of water per minute.

PROCEDURE:

1. Percentage moisture required equals the difference between the optimum moisture content and the moisture content of the raw soil plus 2 per cent to compensate for dry cement added:
$$14 - 6 + 2 = 10 \text{ per cent.}$$
2. Enter Fig. 82 at 9-ft. width of processing and proceed horizontally until 6-in. depth line is intersected.
3. Then proceed vertically downward until 100-lb. density line is intersected.
4. Then proceed horizontally to the right and read 0.54 gal. per lin.ft. per 1 per cent moisture.
5. Multiply this by the 10 per cent moisture required:
$$10 \times 0.54 = 5.4 \text{ gal. per lin.ft.}$$
6. Continue horizontally until the travel speed line of 30 ft. per minute is intersected.
7. Then proceed downward and read 16 gal. per minute per 1 per cent moisture.
8. Multiply this by 10 per cent moisture required:
$$16 \times 10 = 160 \text{ gal. per minute.}$$

Fig. 84. Soil-cement at optimum moisture casts readily when squeezed in the hand and can be broken into two pieces without crumbling.

hand-squeeze test for moisture content. With a little experience, the moisture content of a soil-cement mixture can be estimated and judged closely by eye and feel. For instance, a mixture near or at optimum moisture content is just moist enough to dampen the hands when packed in a tight cast. Mixtures above optimum will leave excess water on the hands whereas mixtures below optimum will crumble and cannot be cast. If the mixture is near optimum, it is possible to break the cast into two pieces with very little crumbling.

The hand-squeeze test is not a replacement for the field-laboratory moisture-content test but it does reduce the number of these tests required during construction. The moisture-determination test validates what has been determined by visual inspection and the hand-squeeze test.

final moisture for compaction and finishing. At the start of compaction the moisture content of the soil-cement mixture must be at optimum moisture or slightly above. A final check of moisture is made at this time. Proper moisture is important because it assists in compaction and is necessary for hydration of the cement. It is more practical to have a slight excess of moisture than a deficiency when compaction begins.

During compaction and finishing the surface mulch may become dry, as evidenced by greying of the surface. Should evaporation losses be noticeable, very

Fig. 85. Greying of the surface during finishing indicates loss of surface moisture. For proper finishing, light applications of water should be made to keep the surface material moist.

small applications of water are made to bring the moisture content to slightly above optimum. A water pressure distributor is used to make these fog applications of water. Proper surface moisture is evidenced by a smooth, moist, tightly knit surface free of checks, cracks or ridges.

uniformity of mix; depth and width of treatment

A thorough, intimate mixture of pulverized soil, cement and water must be obtained to make quality soil-cement. The uniformity of mix is checked by digging trenches or a series of holes at regular intervals for the full depth of treatment across the area being processed and then inspecting the color of the exposed material. When the mixture is of uniform color from top to bottom a satisfactory mix has been attained. Material that has a streaked appearance is not thoroughly mixed.

Depth of mixing is usually checked at the same time. Usually 8 to 9 in. of loose mix will produce about 6 in. of compacted thickness. This varies slightly with the type of soil being processed. Routine depth checks should be made during mixing operations to assure that the specified thickness is attained.

Line stakes set 1 ft. outside the desired roadway edge are used to control width of processing.

degree of compaction and final depth check

The density of a section built the first day should be determined at several locations after final rolling is completed. Comparison of these densities with the results of the field moisture-density test indicates any adjustments in compaction procedures that may be required. Generally specifications require that the density obtained shall not be less than 5 lb. below the maximum density as determined by the field moisture-density test. After compaction procedures have been corrected, only routine daily density checks are required.

A density test is made by drilling or digging a 5-in. diameter hole the full depth of processing; all material removed is carefully salvaged. The wet weight,

Fig. 86. Uniform color indicates thorough mixing.

Fig. 87. Frequent depth checks should be made.

Fig. 88. Final depth check is made by measuring the thickness of treatment through the density hole.

moisture content and oven-dry weight of this material are determined. The volume of the excavated hole can be determined by various methods which are basically the same: The hole is filled with a material of known density and the volume is calculated from the weight of the material used to fill the hole. The density is determined by dividing the dry weight of soil-cement removed from the hole by the volume of the hole.

While a density determination is being made, the depth of processing is measured. Usually the bottom of treatment is quite apparent because of the difference in color between the subgrade and the wet soil-cement mixture. However, sometimes it is hard to distinguish the bottom of treatment by color; in this event water is poured into the density hole and allowed to stand. The subgrade will be

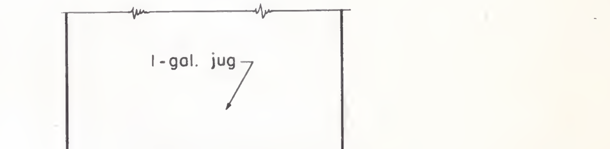

Fig. 89. Sand-cone density apparatus.

softened while the full depth of treatment will remain firm. Then the bottom of treatment can be determined by probing with a pointed instrument.

The most common methods used for the volume determination of the density hole are:

1. Sand-cone method.
2. Oil method.
3. Balloon method.

If the test is performed with care, these and other methods can be used satisfactorily to determine the degree of compaction obtained. Various types of apparatus are available for all these methods. Oven-dry densities are used as comparison with the degree of compaction obtained. However, a rough check on the degree of compaction can be made quickly by comparing wet densities. The sand-cone method is one of the most common and is a standard method of test, AASHO Designation: T 147.

sand-cone method. Figs. 89 and 90 show the apparatus. The sand should be clean, dry, and free-flowing. Sand passing a No. 20 sieve and retained on the No. 30 is most suitable. However, any rounded sand passing the No. 10 sieve and retained on the No. 200 sieve may be used. Standard testing sands may be purchased. The procedure for making the test is as follows:

CALIBRATION OF SAND:

1. Determine the weight of the density apparatus.
2. Pour standard sand into the inverted apparatus through the open valve until the jug and the pycnometer top are full. During this operation the 6½-in. funnel shall be approximately half full of sand at all times. Avoid jarring or vibrating the density apparatus while sand is flowing in it and until the opening in the valve has been closed. Remove the excess sand in the 6½-in. funnel. Weigh the apparatus and sand and determine the net weight of sand. Remove the sand from the density apparatus.

Fig. 90. Equipment for field density and depth checks.

Fig. 91. All material removed from the density hole should be carefully saved.

3. Determine the volume of the 1-gal. jug and pycnometer top with water. Pour water into the inverted density apparatus through the open valve until water appears in the funnel. Close the valve, remove excess water and dry the funnel and outside surfaces of the apparatus. Weigh the apparatus and the water and determine the net weight of water. Remove the water from the density apparatus. and dry the apparatus.

CALIBRATION OF FUNNEL:

1. To determine the weight of sand required to fill the 6½-in. funnel, turn the density apparatus full of sand upright, with the funnel down, on a smooth, flat surface; then open the valve until the sand stops flowing. Close the valve, remove the apparatus and weigh the sand that filled the funnel.

DENSITY TEST:

1. Make the surface of the test area smooth and flat. Dig a hole approximately 5 in. in diameter through the depth of treatment, using a soil auger or hammer and chisel. Material should be loosened in the test hole by cutting, to avoid enlargement of the hole by pressure of the excavating tools. Remove all loosened material in the test hole and place it in a tightly covered container. Clean the hole with a brush and remove all loose particles. Use care during the test to avoid losing any material removed from the test hole.
2. Determine the volume of the test hole by the use of the density apparatus and calibrated sand. Fill the 1-gal. jug with the sand and weigh the apparatus and sand. Place the apparatus, with the 6½-in. funnel down-

Fig. 92. Volume of test hole is measured by the sand-cone density apparatus. Avoid jarring or vibrating the apparatus during test.

ward, over the test hole. Open the valve and allow the sand to fill the test hole and funnel. Avoid jarring or vibrating the density apparatus during the test. After the sand has stopped flowing, close the valve and weigh the apparatus and remaining sand. Determine the net weight of sand used to fill the hole and funnel.

3. Determine the moist weight of all material removed from the test hole. Mix material thoroughly and take a representative sample for moisture determination. Dry the moisture sample to constant weight and determine the dry weight of material removed from test hole.
4. Determine the percentage of rock retained on the No. 4 sieve of the material removed from the test hole.

CALCULATIONS:

1. The unit weight of the sand in pounds per cubic foot is equal to the pounds of sand required to fill the jug and pycnometer top divided by the volume of the jug and pycnometer top. The volume of the jug and pycnometer top is equal to the pounds of water used to fill it divided by 62.4 lb.—the unit weight of water per cubic foot.
2. The moisture content and the oven-dry weight of material removed from the test hole are calculated as follows:

$$\text{Per cent moisture} = \frac{\text{Wet weight} - \text{dry weight}}{\text{Dry weight}} \times 100.$$

$$\text{Dry weight of material} = \frac{\text{Wet weight}}{100 + \text{per cent moisture}} \times 100.$$

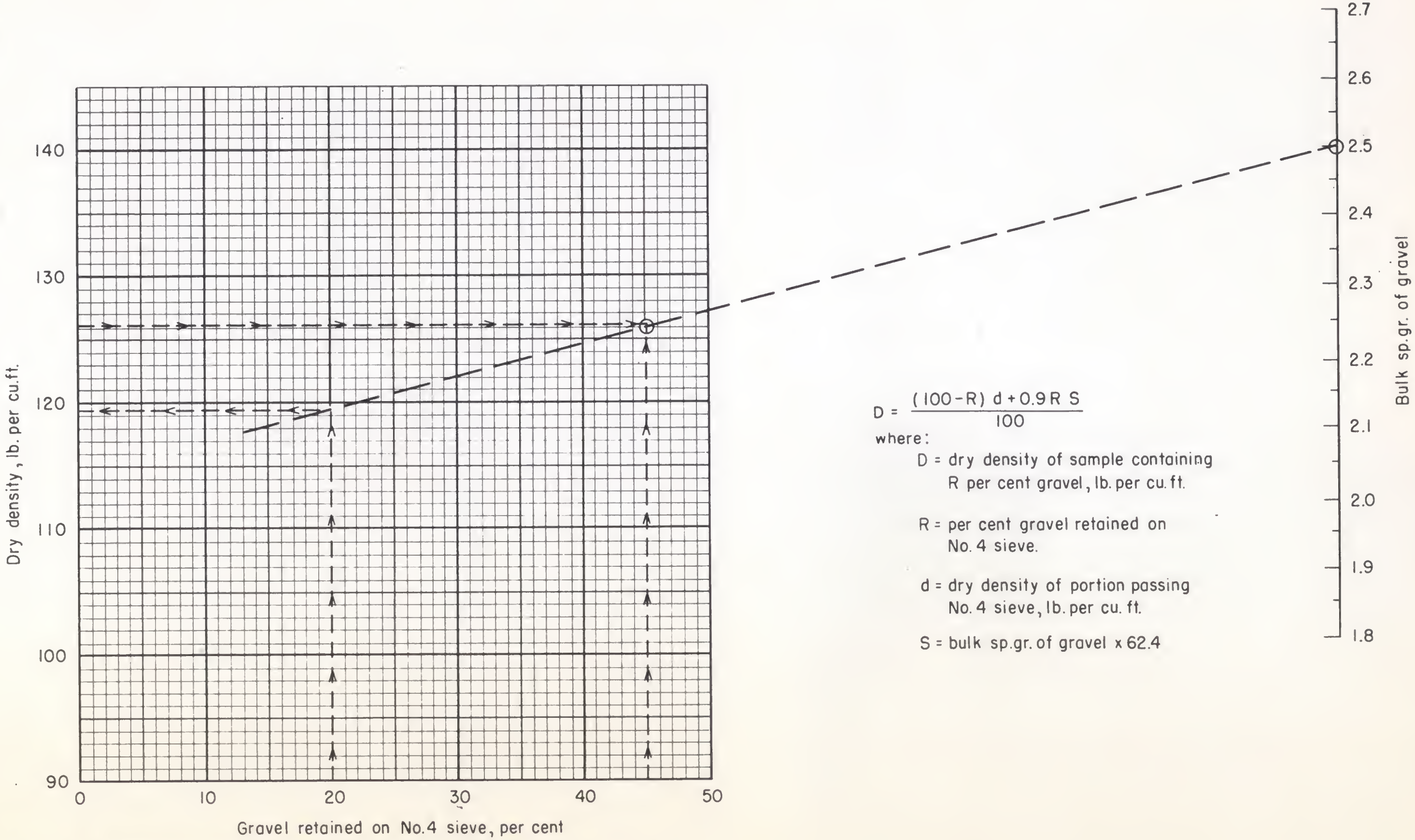

Fig. 93. Density correction chart for differences in gravel content.

3. The in-place, oven-dry density in pounds per cubic foot of the material tested equals the dry weight in pounds of the material removed from the test hole divided by the volume of the test hole in cubic feet.

Occasionally, field densities of soils and soil-cement mixtures containing large percentages of gravel are difficult to check with the moisture-density test results. This may be because the percentage of gravel in the material taken from the density hole is lower or higher than that in the sample used in the moisture-density test. This difference in density caused by a difference in gravel content can be corrected by using Fig. 93.

example 1.

GIVEN: Percentage of gravel larger than No. 4 sieve in moisture-density test sample..45 per cent.
Percentage of gravel larger than No. 4 sieve in sample from field density test..20 per cent.
Bulk specific gravity of gravel..2.50*
Maximum density from field moisture-density curve determined on sample containing 45 per cent gravel
.... 126.2 lb. per cu.ft.

PROCEDURE: 1. On the grid, Fig. 93, locate the intersection of 126.2 lb. per cu.ft. dry density and 45 per cent gravel.
2. With a straightedge, intersect this point and the specific gravity of 2.50.
3. Project this line until it intersects the vertical line on the grid representing 20 per cent gravel.
4. Project this point horizontally to the dry density scale.

ANSWER: The density of 119.6 lb. per cu.ft. is the corrected maximum dry density of the field moisture-density test for a sample containing 20 per cent gravel instead of 45 per cent gravel. The in-place dry density of the material tested should be compared to this corrected density since both samples contain the same percentage of gravel.

record of field density tests. A record of density and depth data should be kept. The form and example shown in Fig. 94 further illustrate the density test and provide a procedure for eliminating errors and for keeping records.

proper finishing

A satisfactory finish must be smooth, dense and free of ridges, cracks and surface compaction planes. This can be achieved easily if the fundamentals described in Chapter 2, page 44, are followed. The project engineer and inspector should be familiar with the various finishing procedures.

adequate curing

Curing is as important as the other construction operations. It is essential for the proper hydration of cement and hardening of the soil-cement mixture. See Chapter 1, page 18.

*Bulk Sp.Gr. of gravel (pycnometer method) $= \dfrac{A}{B+Y-Z}$

A = oven-dry wt. of gravel, gr.
B = saturated surface-dry wt. of gravel, gr.
Y = wt. of pyc. filled with water, gr.
Z = wt. of pyc. and saturated surface-dry gravel, and filled with water, gr.

Sample No. ____________________ Project No. ____________________

Station ____________________ Route ____________________

Location ____________________ Date built ____________________

Date tested ____________________

CALIBRATION OF SAND:

1.	Weight of sand-cone density apparatus filled with air-dry sand	17.91	lb.
2.	Weight of apparatus	4.20	lb.
3.	Weight of air-dry sand (1)—(2)	13.71	lb.
4.	Weight of apparatus filled with water	12.75	lb.
5.	Weight of apparatus	4.20	lb.
6.	Weight of water (4)—(5)	8.55	lb.
7.	Volume of apparatus (6) ÷ (62.4*) .... 8.55 ÷ 62.4 =	0.1371	cu.ft.
8.	UNIT WEIGHT OF SAND (3) ÷ (7) ... 13.71 ÷ 0.1371 =	100.0	lb. per cu.ft.

CALIBRATION OF FUNNEL:

9.	Weight of apparatus and sand at start	17.91	lb.
10.	Weight of apparatus and unused sand	13.98	lb.
11.	Weight of sand to fill funnel (9)—(10)	3.93	lb.

VOLUME DETERMINATION OF HOLE:

12.	Weight of apparatus and sand at start	17.91	lb.
13.	Weight of apparatus and unused sand	6.46	lb.
14.	Sand used (12)—(13)	11.45	lb.
15.	Less weight of sand in funnel (11)	3.93	lb.
16.	Weight of sand to fill hole (14)—(15)	7.52	lb.

17. VOLUME OF HOLE =

$$\frac{\text{Wt. of sand to fill hole}}{\text{Unit weight of sand}} : \frac{(16)}{(8)} = \frac{7.52}{100.0} = 0.0752 \text{ cu.ft.}$$

MOISTURE DETERMINATION AND WEIGHT OF MATERIAL FROM TEST HOLE:

18.	Moisture sample No. 1		
19.	Wet weight of sample and container	1697.5	gr.
20.	Dry weight of sample and container	1626.0	gr.
21.	Weight of container	876.0	gr.
22.	Moisture loss	71.5	gr.
23.	Dry weight of sample	750.0	gr.

24. Per cent moisture =

$$\frac{\text{Moisture loss}}{\text{Dry wt. of sample}} : \frac{(22)}{(23)} \times 100 = 9.5 \text{ per cent}$$

25. Wet weight of material from test hole .... 10.12 lb.

26. Dry weight of material from test hole =

$$\frac{\text{Wet weight}}{\text{100 plus per cent moisture}} : \frac{(25)}{100 + (24)} = \frac{10.12}{100 + 9.5} = 9.25 \text{ lb.}$$

27. Per cent plus No. 4 sieve size gravel in material from test hole .... 20 per cent

28. DRY DENSITY =

$$\frac{\text{Dry wt. of test hole material}}{\text{Volume of test hole}} : \frac{(26)}{(17)} = \frac{9.25}{0.0752} = 123.0 \text{ lb. per cu.ft.}$$

COMPARISON OF DENSITIES:

29.	Max. density from field curve	126.2	lb. per cu.ft.
30.	Per cent plus No. 4 sieve size gravel in moisture-density sample	45	per cent
31.	Bulk Sp.Gr. of gravel	2.50	
32.	Corrected density for 20 per cent gravel (Fig. 93)	119.6	lb. per cu.ft.
33.	DEGREE OF COMPACTION (28)—(32) = 123.0—119.6 =	+3.4	lb.

DEPTH:

34. Depth of treatment through test hole .... 6¼ in.

*1 cu.ft. of water = 62.4 lb.

Tested by ____________________

Fig. 94. Form to use in making field density test.

field-testing equipment

1. Portable shed, 8x10 ft. (A converted trailer makes an excellent field laboratory.)
2. Two-burner stove and gasoline.
3. Split moisture-density mold and rammer (1/30-cu.ft. mold; sleeved 5½-lb. rammer).
4. Balance with weights, 750-gram capacity, sensitive to 1/10 gram.
5. Scale with weights, 20-lb. capacity, sensitive to 1/100 lb.
6. Three 3x3-ft. pieces of canvas.
7. Spring scale, 100-lb. capacity.
8. Set of 8-in. diameter sieves, 3 in., ¾ in., Nos. 4, 10 and 20.
9. Sand-cone density apparatus with supply of dry sand of known unit weight.
10. 5-in. diameter soil auger and No. 2 short-handled, square-pointed shovel.
11. Hammer and two 1-in. mason's chisels.
12. Six tin pie plates and six ½-gal. syrup pails.
13. Two 10-in. diameter frying pans.
14. 100-cc glass graduate.
15. 10-in. butcher knife, 12-in. steel straightedge and 10-in. trowel.
16. Two 12-qt. pails, two large spoons and a 2-in. paintbrush.
17. 5x5-ft. canvas sample cloth.
18. Ruler and 50-ft. metallic tape.
19. Slide rule, notebook, graph paper, pencils and paper, etc.

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